ERDC/CHL TR-02-15

Coastal and Hydraulics Laboratory

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GREENUP Environmental Mitigation, R. C. Byrd Locks and Dam, Ohio River

Navigation Model Study

Randy A. McCollum

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by Randy A. McCollum

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Final report

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Prepared for U.S. Army Engineer District, Huntington
502 8th Street, Huntington, WV 25701-2070

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Preface

This study was conducted for the U.S. Army Engineer District, Huntington, in the Coastal and Hydraulics Laboratory (CHL), of the U.S. Army Engineer Research and Development (ERDC), Vicksburg, MS, during the period April through December 2001.

During the course of the model study, representatives of the Huntington District visited ERDC to observe model operations and discuss experiment results. The Huntington District was kept informed of the progress of the study through monthly progress reports, periodic e-mail and telephone conversations, briefings, and letter reports on key segments of the model testing during the course of the study.

The investigation was conducted under the general supervision of Mr. Thomas W. Richardson, Director, CHL, Mr. Thomas J. Pokrefke, former Acting Assistant Director, CHL, and under the direct supervision of Dr. Sandra K. Knight, Chief, Navigation Branch, and Dr. John E. Hite, former Acting Chief, Navigation Branch, CHL. The Principal Investigator in charge of the model and preparation of the report was Mr. Randy A. McCollum, assisted by Mr. B. T. Crawford, both of the Navigation Branch.

Dr. Stephen T. Maynord, also of the Navigation Branch, was consulted and assisted in the evaluation of stone sizing required for the proposed dikes that is documented in the appendix.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

Conversion Factor, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
cubic feet	0.02831685	cubic meters

1 Introduction

Greenup Locks and Dam, completed in 1962, is located on the Ohio River at river mile 341. The existing structure consists of two lock chambers, a riverward 110-ft × 1,200-ft[1] main chamber and a landward 110-ft × 600-ft auxiliary chamber. Extension of the auxiliary chamber has been proposed to alleviate potential lockage problems.

Mitigation proposals have been established to offset environmental impacts as a direct result of proposed projects currently under investigation as part of the Ohio River Main Stem System (ORMSS). One of these proposals is the introduction of longitudinal vane dikes downstream of the existing navigation dam at R. C. Byrd Locks and Dam, river mile 279.2. It is proposed to construct two, 1,000-ft-long rock dikes in order to provide habitat for various species. These dikes will serve as replacement habitat units for those affected due to implementation of ORMSS projects. The dikes are to be situated in the existing channel, no closer than 400 lin ft downstream of existing roller gate piers. In order to lessen operation and maintenance of the navigation dam, the dikes will be centered on two of the existing gate piers.

The U.S. Army Engineer District, Huntington, requested that the existing 1:120 navigation model of R.C. Byrd be used to accomplish the following tasks:

a. Document lower pool navigation conditions for both existing and proposed modifications.

b. Document potential bed-load movements that may have an impact on the stability of the structures (i.e., undermining, scour, etc.), thereby, compromising the ability to navigate below the dam while conducting maintenance or other necessary functions of operation.

c. Document any noticeable adverse impacts due to introduction of the project features may have an impact on the day-to-day operation and maintenance of the existing navigation project.

d. Provide recommendations for stone gradations capable of withstanding high flow conditions.

[1] A table for converting non-SI units to SI units of measurement can be found on page vi.

To accomplish the requested tasks, the Navigation Branch of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), proposed the following:

a. Document the existing (base) and proposed plan conditions with current directions and velocities and tow tracks for four flow conditions (75,000, 150,000, 300,000, and 466,000 cfs).

b. Bed-load movements cannot be evaluated quantitatively in a fixed bed model. Visualization of flow patterns with photographs using dye and confetti and visualization of bed-load movement by using a plastic tracer material (beads) was performed to provide a qualitative analysis. Point velocities taken at mid- and near-bottom depths using an electromagnetic flow meter were used to document velocities in and around the dike field and into the downstream approach to the locks with two flow conditions for both base and plan conditions. This data will be used to determine if there are any adverse impacts to navigation conditions and in analyzing the size of stone required for the dikes.

2 Model Experiments and Results

Reactivation and Water-Surface Comparisons

The R.C. Byrd navigation model, which had not been operated since 1995, was cleaned and restored to the existing (base) conditions by reinstalling the downstream guide and guard walls of the old locks adjacent to the dam. The four flow conditions that were used for testing (75,000-, 150,000-, 300,000-, and 466,000-cfs) were then reproduced in the model, using the same model discharge, tailwater elevation, and dam gate openings (where applicable) as the flows in 1995 and the water-surface elevations[2] in the model recorded and compared to the 1995 elevations. Figure 1 shows the location at which water-surface elevations were recorded. The comparisons of the water-surface profiles for the base conditions in 1995 and those obtained in May 2001 are as follows:

75,000 cfs		
Gauge No.	**1995 elevations**	**2001 elevations**
1	537.9	537.8
2	537.9	537.4
3	523.2	523.1
4	-	522.6
5	522.7	522.6
- Not recorded		

150,000 cfs		
Gauge No.	**1995 elevations**	**2001 elevations**
1	538.1	537.9
2	537.8	537.4
3	531.0	531.1
4	530.5	530.6
5	530.6	530.6

[2] All elevations (el) cited herein are in feet referenced to the Ohio River Datum (to convert feet to meters, multiply number of feet by 0.3048).

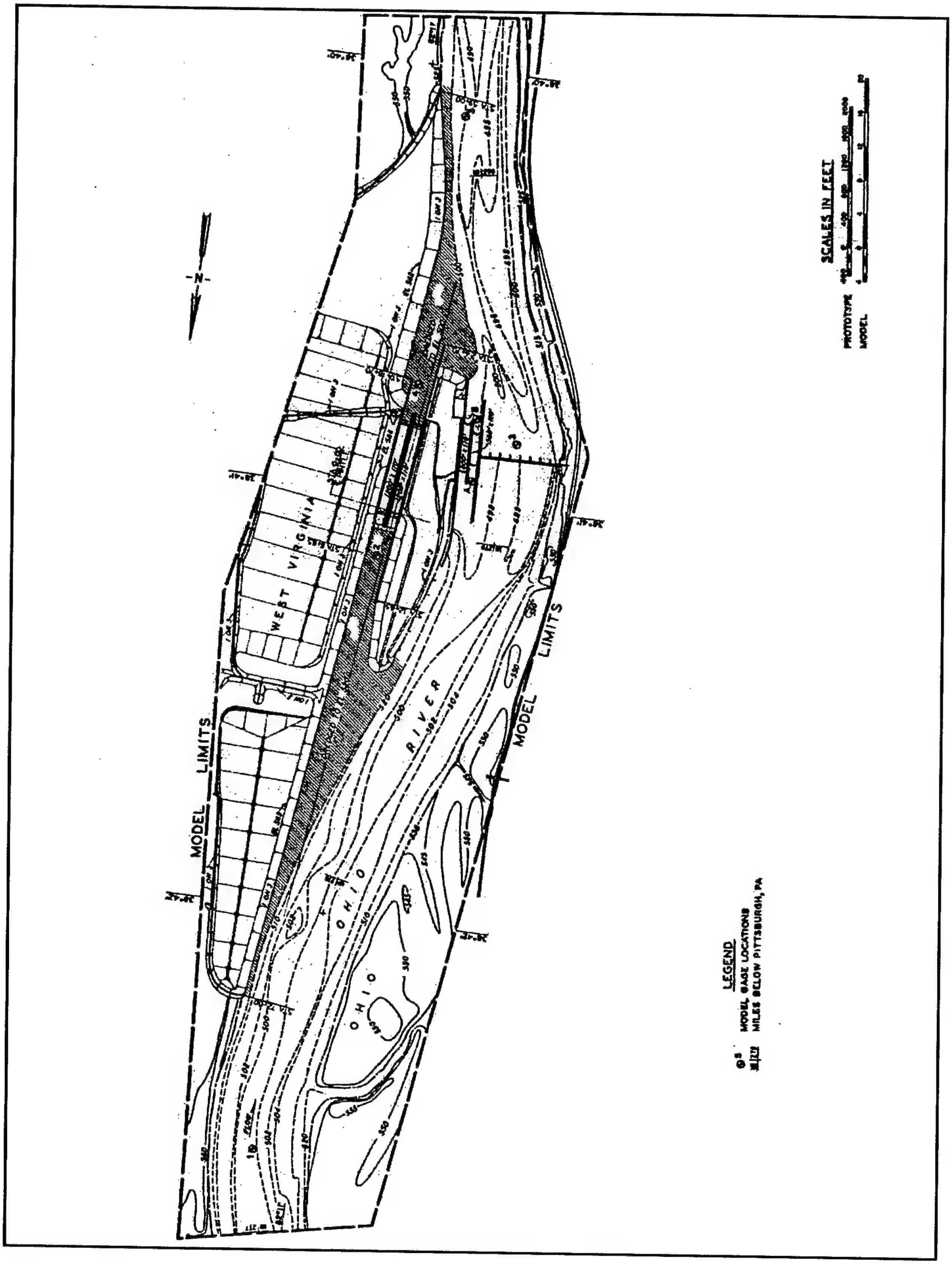


Figure 1. Model layout

300,000 cfs		
Gauge No.	1995 elevations	2001 elevations
1	546.0	546.2
2	545.7	545.6
3	545.0	544.9
4	544.5	544.5
5	544.5	544.5

466,000 cfs		
Gauge No.	1995 elevations	2001 elevations
1	559.3	559.5
2	559.2	559.2
3	558.4	558.3
4	557.5	557.4
5	557.8	557.7

Comparison of the water-surface elevations shows that the model replicated conditions from the previous period of operation in 1995, especially in the lower pool in the area of interest. This indicated that the model was in good condition as compared to the last operations performed in 1995 and results from the model would be as good as those from the 1995 testing.

Base Conditions

Description

Once it was established that the model was reproducing flow conditions accurately as compared with the 1995 operations, current directions and velocities and tow tracking were performed with the existing (base) conditions. Since the area of interest was only in the lower pool, there was no data recorded in the upper pool.

To document the navigation conditions, current directions and velocities, and tow tracking were performed. Current directions and velocities are obtained by tracking of lighted floats, weighted to draft 9 ft, throughout the model by means of video tracking equipment mounted over the model. The cameras of the video tracking system are calibrated to provide a north and east state plane coordinate and a time stamp for each light. Velocities and directions are calculated using the total distance traveled by an individual light and the total time the light took to travel over a specified interval. This information is provided as velocity vector plots, showing the direction of the current and listing the magnitude of the current. Tracking of the tows is also performed with the video tracking system. Lights were placed on the center line of a 15-barge tow, 50 ft from the head of the tow and 125 ft from the rear of the barge string, leaving 800 ft between the lights. The tow is maneuvered through the channel as the tracking system is operated. The tracking system again records the position and time-step of the

two lights mounted on the tow. This information is later processed to provide the position of the tow and its speed and heading. This information is provided as a plot, showing the position of the tow at specified intervals during its transit.

A radio-controlled towboat and barges were used to evaluate and demonstrate the effects of currents on navigation. The towboat was equipped with twin screws, Kort nozzles, forward and reverse rudders, and powered by two small electric motors operating from batteries in the tow. The speed of each engine and direction of the rudders were remote-controlled and the towboat could be operated in forward and reverse at speeds comparable to those that could be expected of typical tows in the study reach. The tow used in the study represented a makeup of fifteen 195-ft-long by 35-ft-wide standard barges, with a 100-ft pusher. This provided an overall size tow of 1,075 ft long by 105 ft wide loaded to a draft of 9 ft. The model towboat provided an accurate representation of the maneuvering characteristics of prototype towboats. The towboat was calibrated to the speed of a comparable size prototype towboat moving in slack water and was powered to operate at 1 to 2 mph above the speed of the currents to maintain rudder control but not overpower the currents. A model tow does not have a specific horsepower rating but is controlled to provide only enough power to keep the tow moving at a speed sufficient to maintain rudder control.

Results, navigation conditions

Current directions and velocities. 75,000 cfs, 522.5 tailwater (TW) – Currents from midchannel to the right bank were generally parallel to the right descending bank line (Plate 1). Flow from gates 1 through 3 of the dam generally veered more toward the left descending bank line after passing the guard wall of the old riverward lock. This created a slow counterclockwise eddy between the left bank and the guard wall of the riverward new lock. Velocities crossing the approach to the locks approximately 1,000 ft downstream of the lower end of the guard wall were from 2.6 to 2.8 fps.

150,000 cfs, 530.5 TW – Currents over most of the channel were generally parallel to the right descending bank line (Plate 2). This current created a large eddy that formed on the left side of the channel from the lower end of the guard wall downstream and toward the left descending bank line for 1,200 ft, then back upstream along the left bank, and finally crossing from the left bank back toward the end of the guard wall. The velocities in the eddy were up to 2.2 fps on the channelward side, 2.2 fps on the left bank side, and 0.4 fps from the left bank to the guard wall. The velocity of currents crossing the lock approach approximately 1,000 ft downstream of the end of the guard wall was from 4.0 to 5.3 fps.

300,000 cfs, 544.5 TW – The currents over most of the channel were generally parallel to the right descending bank line (Plate 3). The current created a large counterclockwise eddy on the left bank side of the channel that started slightly downstream of the lower end of the guard wall, extended downstream and slightly riverward of the alignment of the guard wall for approximately 1,200 ft before turning toward the left descending bank line, then ran upstream along the left bank, and finally crossed back toward the lower end of the guard wall. Velocities in the eddy were up to approximately 4.0 fps on the riverward

side, 2.5 fps along the lower end of the eddy, 3.2 fps coming upstream along the left bank, and 1.6 fps crossing from the left bank toward the end of the guard wall. Velocities crossing the lock approach approximately 1,300 ft downstream of the end of the guard wall were from 5.3 to 7.6 fps.

466,000 cfs, 557.5 TW – The currents were generally parallel to the right descending bank line (Plate 4). A counterclockwise eddy formed that extended from slightly downstream and riverward of the lower end of the guard wall, riverward for 300 ft, then turned to parallel the currents until intersecting the left bank line approximately 1,500 ft downstream of the end of the guard wall, moved upstream along the left bank approximately 300 ft, then turned and run upstream toward the downstream end of the guard wall. Two small clockwise eddies formed in the area between the left bank, the end of the guard wall, and the large eddy. The velocities of the large eddy were up to 3.8 fps on the channelward side, 2.6 fps on the downstream end, 1.6 fps on the left bank side, and 1.0 fps on the upstream end. The maximum velocity of the most downstream of the two smaller eddies was 2.6 fps and on the smaller eddy, 0.4 fps. The velocities crossing the lock approach approximately 1,400 ft downstream of the end of the guard wall were up to 8.3 fps.

Tow tracks, upbound. 75,000 cfs, 522.5 TW – There was little difficulty entering either lock. The tow was steered slightly into the current and toward the end of the river lock guard wall (Plate 5). As the head got to within about one-half tow length, the tow could be steered right and the head turned inside the guard wall. There was no problem getting the head on the guard wall and going down into the river lock. For the land lock, the tow could be allowed to set a little more toward the right bank before the head reached the end of the guard wall (Plate 6). Once the head of tow was between the end of guard wall and the bank, little current set was noted and there was no difficulty getting onto the guide wall and into the lock.

150,000 cfs, 530.5 TW – There was no significant difficulty in the approach to either lock. The current set noted on downbound runs required that the tow be steered more into the current to control the set toward the left descending bank. The approach to the river lock (Plate 7) was the same as with 75,000 cfs. Once the head of tow was almost on the guard wall, the current set was greatly diminished and getting on the wall and into the lock was not difficult. For the landward lock (Plate 8), the approach was the same as with the river lock, except that the tow was allowed to drift slightly further toward the left bank. Once the tow was down between the bank and the river lock guard wall, it was noted that the eddy in the approach was stronger and tended to push the tow toward the guard wall. This set was not bad and it was not difficult to get the head on the guide wall and into the lock.

300,000 cfs, 544.5 TW – To the riverward lock (Plate 9), the tow had to be steered into the current to control the set toward the left bank. The tow was worked over to keep the head aligned with the end of the guard wall. As the head got to within 200-300 ft, the tow was steered right to bring the head inside the wall to get it onto the wall. The eddy helped get the head on the wall and pushed the tow onto the wall. There was no problem getting on the wall and into the lock. For the landward lock (Plate 10), the approach was the same as the

river lock, except that the tow was allowed to set further toward the left bank. As the head of the tow passed inside the end of the guard wall, the eddy set pushed the tow toward the guard wall. This had to be steered against to keep the head in alignment with the riverward lock. The stern of the tow tended to be out near the river lock guard wall as the head reached the river lock guide wall. The tow could be worked into the lock without excessive difficulty.

466,000 cfs, 557.5 TW – Into the riverward lock (Plate 11), the tow worked directly upstream into the current. As the tow got about two lengths from the end of the guard wall the current was almost completely diminished. There was no problem getting onto the guard wall and staying there as the tow moved into the lock. Into the landward lock (Plate 12), the approach was the same except once the tow got out of the current it had to be driven further toward the left descending bank line. The eddy across the lock approach from the left bank to the guard wall tended to set the tow channelward. This tended to make the tow to be angled slightly away from the guide wall when the tow made contact with the end of the wall. It was not overly difficult to pull the stern up toward the left bank once the head was on the guide wall and the tow got into alignment to go into the lock.

Tow tracks, downbound. 75,000 cfs, 522.5 TW – There was no difficulty going downbound from the riverward lock (Plate 13). There was almost no set as the head of the tow cleared the downstream end of the guard wall and no difficulty getting out into the channel. There was no difficulty going downbound from the landward lock (Plate 14). There was no apparent eddy set between the bank and the river lock guard wall and only a little current set as the tow passed outside the guard wall.

150,000 cfs, 530.5 TW – The tow moved along the guard wall of the riverward lock with no difficulty and there was little current influence as the head of the tow passed the end of the wall (Plate 15). There was more current set about one tow length downstream of the guard wall than noted with the 75,000-cfs flow, but it was not difficult to maneuver against. From the landward lock (Plate 16) the tow could be turned slightly after getting out of the lock and past the guide wall before the tow got out into any current. There was no problem maneuvering in the crosscurrent in the approach.

300,000 cfs, 544.5 TW – From the riverward lock (Plate 17), the eddy at the end of the guard wall kept the tow on the wall. The tow was driven out along the wall almost completely before the tow could be maneuvered. There was no problem getting out into the channel and maneuvering against the crosscurrent. From the landward lock (Plate 18), it wasn't difficult to angle the tow slightly right to compensate for the current set and get out into the channel once the tow cleared the chamber.

466,000 cfs, 557.5 TW – From the riverward lock (Plate 19) there was no difficulty getting off the guard wall and out into channel. Only when tow was about two lengths downstream of the end of the guard wall did strong current tend to set the tow, but it was not difficult to get out into the channel and be prepared for it before getting there. From the landward lock (Plate 20), it was even easier. The tow was easily angled toward the end of the guard wall after

clearing the lock and could be driven well out across the channel before getting caught in the strong current.

Preliminary Evaluation of Vane Dike Placement

Description

Figure 2 shows the details of the proposed vane dikes. The crest elevation is to be 2 ft above the normal pool elevation, which in this case is el 517.0. Originally, the Huntington District indicated the dikes would be perpendicular to the axis of the dam, aligned with piers 3 and 6 of the dam, and would start no closer than 400 ft downstream of the end sill of the stilling basin. After further discussions with the Huntington District, it was determined that the upstream end of the dikes should be no closer than 600 ft to the end sill. Using the same alignment for the dikes as proposed, building the dikes 1,000 ft long, and starting the dikes at 600 ft downstream of the end sill would place the downstream end of the right dike (aligned with pier 6 of the dam) well onto the right descending bank line.

A preliminary design was suggested by ERDC that would place the upstream ends of the proposed dikes 600 ft downstream of the end sill and aligned with a perpendicular extension off the dam center line through piers 3 and 6, make the dikes 1,000 ft long, and angle the dikes to be parallel to the right descending bank line. This was done to provide approximately the same cross-sectional area from the right dike to the right bank at both the upper and lower end of the dike.

To evaluate the effectiveness of this design, temporary training works (in this case, brick) were placed in the model to the correct alignment and length. The brick approximated the correct elevation and toe width but did not replicate the roughness and side slope of the proposed dikes. These were placed in the model to look for general changes in current patterns and in the operation of the model tow as compared to the base conditions that would indicate potential navigation problems that would require design modifications.

To evaluate the preliminary design, the 150,000- and 300,000-cfs flow conditions were replicated in the model. During base conditions documentation, these two flows were noted to have the most difficult navigation conditions of the four flows used. Current directions and velocities were recorded with the overhead tracking system and the model tow was operated, but not recorded.

Results

Comparison of the current directions and velocities recorded with the preliminary dike plan (Plates 21 and 22) and the base conditions (Plates 2 and 3) indicate that the size of the eddy formed in the lock approach is about the same, although slightly higher velocity at 150,000 cfs and the eddy somewhat larger but slightly slower moving from the right bank toward the end of the guard wall for the 300,000 cfs flow velocity for the preliminary dike design. Operations of

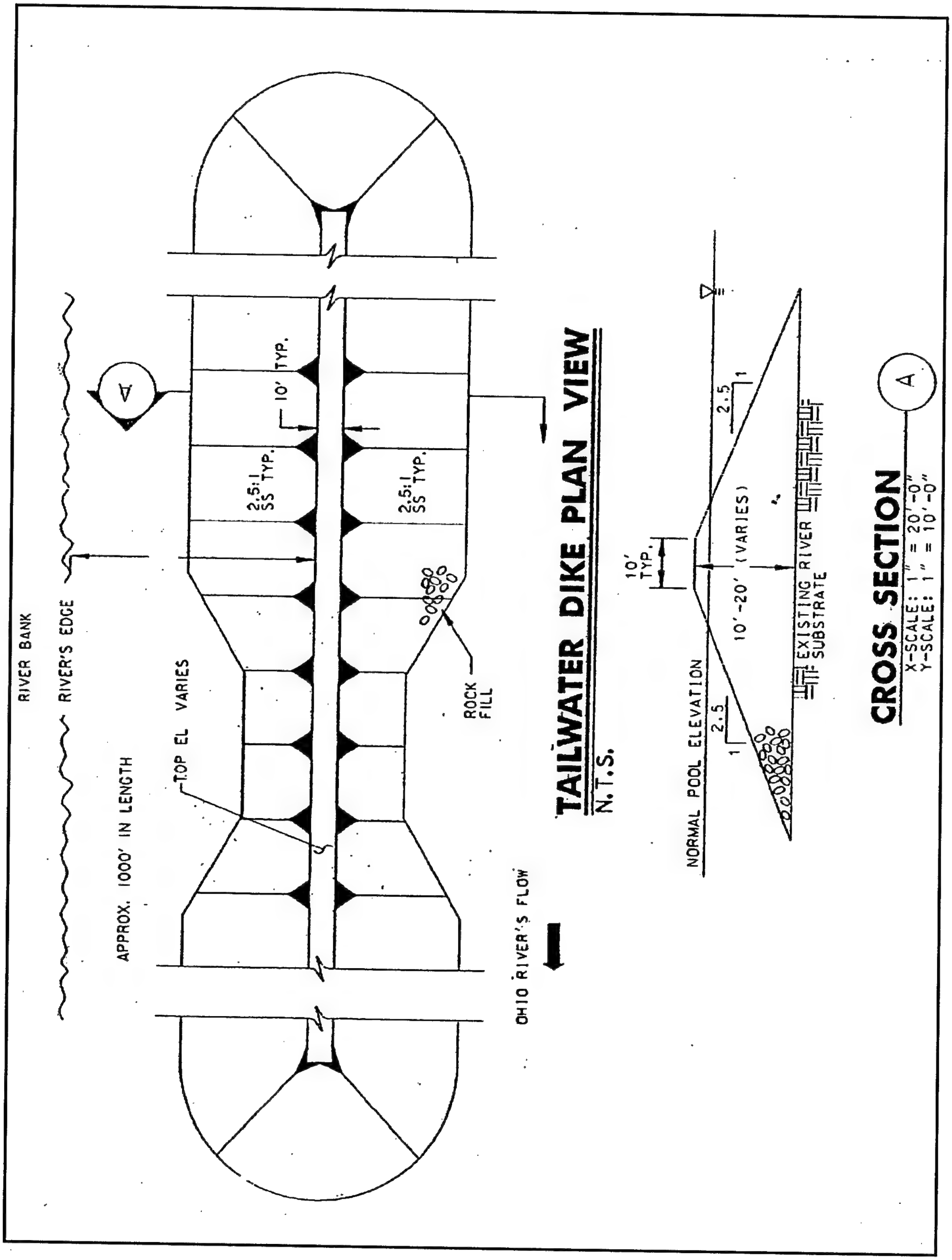


Figure 2. Vane dike details

the model tow did not suggest any significant change in the level of difficulty in upbound or downbound transits with the preliminary design versus the base conditions.

Plan A Conditions

Description

After determining that the preliminary dike design did not appreciably change navigation conditions in the lower lock approach, the temporary dikes were removed and dikes were constructed of crushed limestone. The dikes were placed in the same alignment as those of the preliminary dikes, each 1,000 ft long, and graded with a crest elevation of el 517.0 and an approximate side slope of 1 on 2.5 (Figure 3). This was designated as Plan A.

Results, navigation conditions

Current directions and velocities. 75,000 cfs, 522.5 TW – The currents generally were parallel to the right descending bank line (Plate 23). An eddy formed in the lower lock approach, starting from the downstream end of the guard wall moving upstream and riverward toward the old locks then downstream along the edge of the straight line currents and worked toward the left descending bank line approximately 800 ft downstream of the end of the guard wall, then upstream along the left bank and gradually moved away from the bank until approximately 300 ft upstream of the end of the guard wall, then turned directly toward the guard wall and moved out along the wall to the downstream end. The maximum velocities in this eddy within the approach to the locks was 2.1 fps on the riverward side, 0.7 fps on the downstream end, 1.5 fps along the left bank and 0.3 fps across the upstream end. The velocities moving across the approach to the lock 1,000 ft downstream of the end of the guard wall were from 2.7 to 4.2 fps.

150,000 cfs, 530.5 TW – The currents were generally parallel to the right descending bank line (Plate 24). An eddy formed in the lock approach that extended from the downstream end of the guard wall, slightly riverward for 500 ft then moved toward the left bank at 1,100 ft downstream of the guard wall, then upstream along the left bank, then turned back toward the end of the guard wall. The maximum velocities in the eddy were 2.9 fps along the riverward side, 0.7 fps on the downstream end, 2.3 fps along the left bank side, and 0.6 fps across the upstream end. The velocities moving across the lock approach 1,000 ft downstream of the end of the guard wall were from 4.5 to 5.8 fps.

300,000 cfs, 544.5 TW – The currents in the channel were generally parallel to the right descending bank line (Plate 25). An eddy formed in the lower lock approach starting from the lower end of the guard wall moving upstream and riverward to the end of the old guard wall, then downstream along the edge of the straight line currents and toward the left bank approximately 1,500 ft downstream of the guard wall, then upstream along the left bank, and finally turning to come

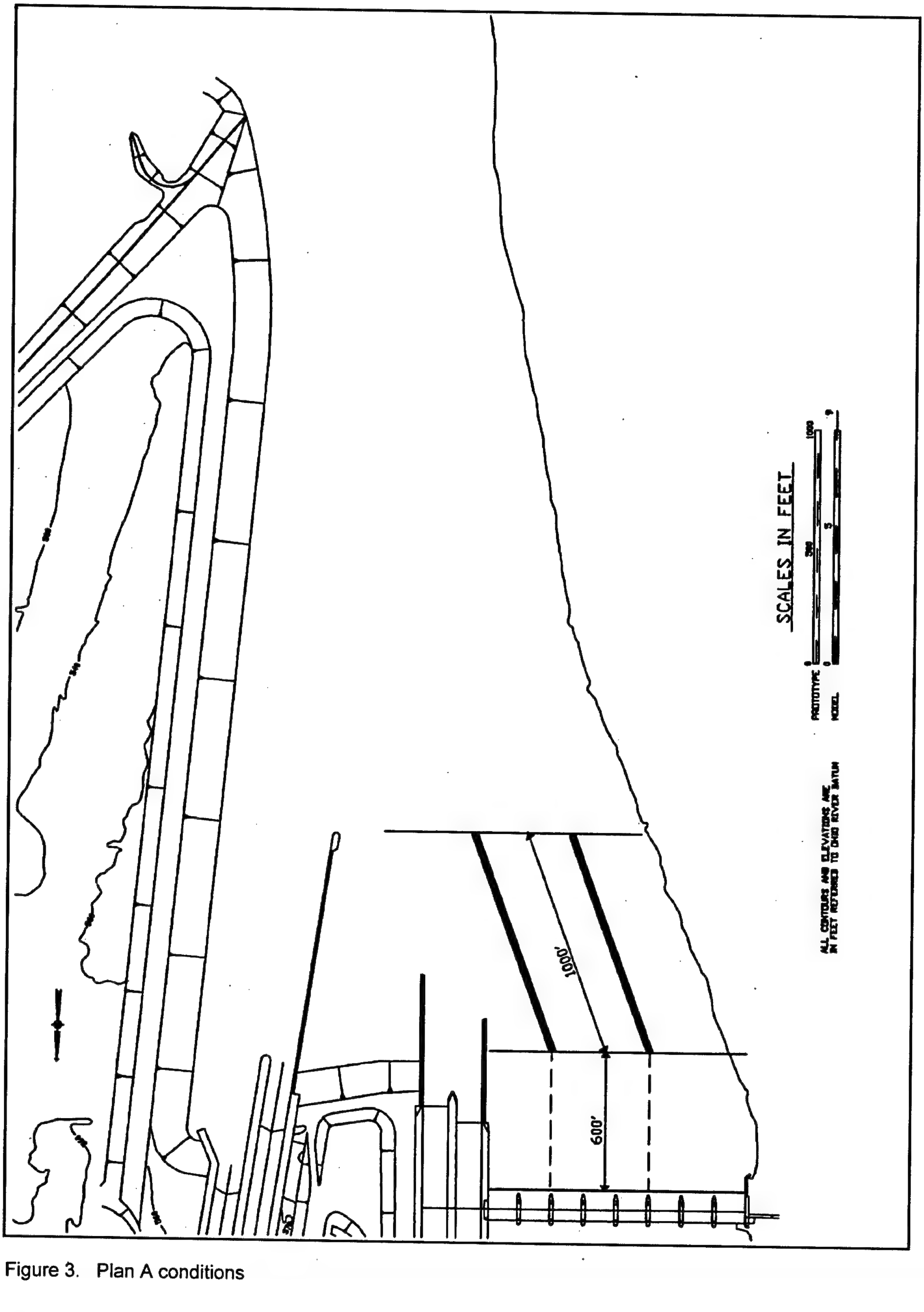


Figure 3. Plan A conditions

back to the end of the guard wall. The maximum velocities in the eddy were 3.9 fps on the riverward side, 1.2 fps on the downstream end, 3.5 fps along the left bank, and 1.2 fps on the upstream end. The velocities moving across the lock approach 1,300 ft downstream of the end of the guard wall were from 5.8 to 8.0 fps.

466,000 cfs, 557.5 TW – The currents in the channel were generally angled slightly toward the right descending bank line for approximately 3,200 ft downstream of the axis of the dam (Plate 26). Two eddies were formed in the lock approach. The first counterclockwise eddy extended from slightly riverward of the end of the guard wall upstream 400 ft toward the guide wall of the old lock, then riverward for 300 ft, then downstream along the edge of the straight line currents toward the left bank 1,400 ft downstream of the end of the guard wall, then upstream angled back toward the end of the guard wall. The second clockwise eddy was formed between the first eddy and the left bank to approximately 300 ft upstream of the end of the guard wall. The maximum velocities in the first eddy were 4.3 fps on the riverward side, 1.7 fps on the downstream end, 1.4 fps along the left bank side, and 0.1 fps on the upstream end. The second eddy had a maximum velocity of 0.8 fps on the riverward side, 0.2 fps on the upstream end, and 0.3 fps on the left bank side. The velocities moving across the lock approach 1,400 ft downstream of the end of the guard wall were from 6.3 to 8.9 fps.

Tow tracks, upbound. 75,000 cfs, 522.5 TW – There was little difficulty entering either lock. The tow was steered slightly into the current and toward the end of the river lock guard wall (Plate 27). As the head got to within about one-half tow length, the tow could be steered right and the head turned inside the guard wall. There was no problem getting the head on the guard wall and going down into the river lock. For the land lock (Plate 28), the tow could be allowed to set a little more toward the right bank before the head reached the end of the guard wall. Once the head of the tow was between the end of the guard wall and bank, little current set was noted and there was no difficulty getting onto the guide wall and into the lock.

150,000 cfs, 530.5 TW – There was no significant difficulty in the approach to either lock. The tow was steered into the current to control the set toward the left descending bank. The approach to the river lock (Plate 29) was the same as with the 75,000-cfs flow. Once the head of the tow was almost on the guard wall, the current set was greatly diminished and getting on the wall and into the lock was not difficult. For the landward lock (Plate 30), the approach was the same as with the river lock, except that you let the tow drift slightly further toward the left bank. Once the tow was down between the bank and the river lock guard wall, it was noted that the eddy in the approach was stronger and tended to push the tow toward the guard wall. This set was not bad and it was not difficult to get the head on the guide wall and into the lock.

300,000 cfs, 544.5 TW – To approach the landward lock (Plate 31), the tow had to be steered into the current to control the set toward the left bank. The tow was worked over to keep the head aligned with the end of the guard wall. As the head got to within 200-300 ft, the tow was steered right to bring the head inside the wall to get it onto the wall. The eddy helped get the head on the wall and pushed the tow onto the wall. It was noted that the eddy seemed to push the tow

into the guard wall more forcefully than with the base conditions, but not excessively so. There was no problem getting on the wall and into the lock. For the riverward lock (Plate 32), the approach was the same as the landward, except that the tow was allowed to set further toward the left bank. As the head of the tow passed inside of the end of the guard wall, the eddy set pushed the tow toward the guard wall. This had to be steered against to keep the head in alignment with the riverward lock. The tow tended to be angled slightly away from the guide wall as the tow made contact with the wall, but the tow could be worked into the lock without excessive difficulty.

466,000 cfs, 557.5 TW – Into the riverward lock (Plate 33), the tow worked directly upstream into the current. As the tow got about two lengths from the end of the guard wall the current was almost completely diminished. The direction of the eddy in the lock approach caused the tow to try to move away from the guard wall, but not enough that it was difficult to get onto the wall and stay on the wall. Into the landward lock (Plate 34), the approach was the same except once the tow got out of the current it had to be driven further toward the left descending bank line. The eddy across the lock approach from left bank to the guard wall tended to make the tow angle slightly away from the guard wall. Once on the wall, it was not difficult to get the tow aligned with the wall and get into the lock. It was not overly difficult to pull the stern up toward the left bank once the head was on the guide wall and got into alignment to go into the lock.

Tow tracks, downbound. 75,000 cfs, 522.5 TW – There was no difficulty coming from the riverward lock (Plate 35). There was almost no set as the head of the tow cleared the downstream end of the guard wall. There was no difficulty getting out into the channel. There was no difficulty coming from the landward lock (Plate 36). There was no eddy set between the bank and the river lock guard wall. There was little current set as the tow passed outside the guard wall.

150,000 cfs, 530.5 TW – There was little difficulty coming from the riverward lock (Plate 37). The tow moved along the guard wall and there was little current influence as the head of the tow passed the end of the wall. There was more current set about one tow length downstream of the guard wall than noted with the 75,000-flow, but it was not difficult to deal with. There was no difficulty coming from the landward lock (Plate 38). The tow could be turned slightly after getting out of the lock and past the guide wall before the tow got out into any current. There was no significant problem dealing with the crosscurrent in the approach.

300,000 cfs, 544.5 TW – From the riverward lock (Plate 39), the eddy at the end of the guard wall kept the tow on the wall. The tow was driven out along the wall almost completely before the tow could be maneuvered. There was little problem getting out into the channel and dealing with the crosscurrent. From the landward lock (Plate 40), it wasn't difficult once the tow cleared the chamber to angle the tow slightly right to compensate for the current set and get out into the channel.

466,000 cfs, 557.5 TW – From the riverward lock (Plate 41) there was no difficulty getting off the guard wall and out into channel. Only when the tow was about two lengths downstream of the end of the guard wall did strong current

tend to set the tow, but it was relatively easy to get out into the channel and be prepared for it before getting there. From the landward lock (Plate 42), it was even easier. The tow was easily angled toward the end of the guard wall after clearing the lock and could be driven well out across the channel before getting set in the strong current.

Point Velocity Comparisons

Description

One task in the request to use the R.C. Byrd model received from the Huntington District was to document potential bed-load movements that may have an impact on the stability of the structures (i.e., undermining, scour, etc.), thereby, compromising the ability to navigate below the dam while conducting maintenance or other necessary functions of operation. Since the model is of a fixed-bed type, the potential for bed scour cannot be examined directly. ERDC suggested that point velocities be collected within the water column in and around the proposed dikes and compared with velocities collected at the same points with the base conditions to help determine the potential for bed material scour.

To document how the addition of the proposed dikes for Plan A would change velocities within the water column as compared with the base conditions, a grid pattern was established around and between the Plan A dikes and in the lock approach starting at the downstream end of the guard wall and extending 1,000 ft downstream (Figure 4). Velocities were collected at six-tenths- and eight-tenths-depth at each of these points using an electromagnetic flow meter. This meter is based on Faraday's Law that a conductor (water) moving in a magnetic field (produced by a coil in the sensor) produces voltage (measured by a pair of electrodes on the sensor). The sampling volume is measured over the sensor (shaped as a disk approximately 1 in. in diameter with the electrodes mounted on the upper surface) in a small cylinder whose diameter is the distance between the electrodes and extends in height approximately 10 mm above the surface of the sensor. Once the velocities were obtained with the dikes in place, the dikes were removed and the velocities were recorded in the same positions with the base conditions. This was performed with the 150,000- and 300,000-cfs flow conditions. The velocities are presented in Tables 1 and 2.

Results

The six-tenths-depth velocities for the 150,000-cfs flow condition (Table 1) indicate some variations between the base and Plan A conditions within the dike field but no significant changes. The velocities recorded in the lock approach were almost unchanged by the addition of the dikes. At the eight-tenths-depth, the velocities in the dike field had some variation between the base and Plan A conditions but nothing of major significance. The velocities in the lock approach were generally the same or slightly lower for the Plan A conditions as compared to the base condition.

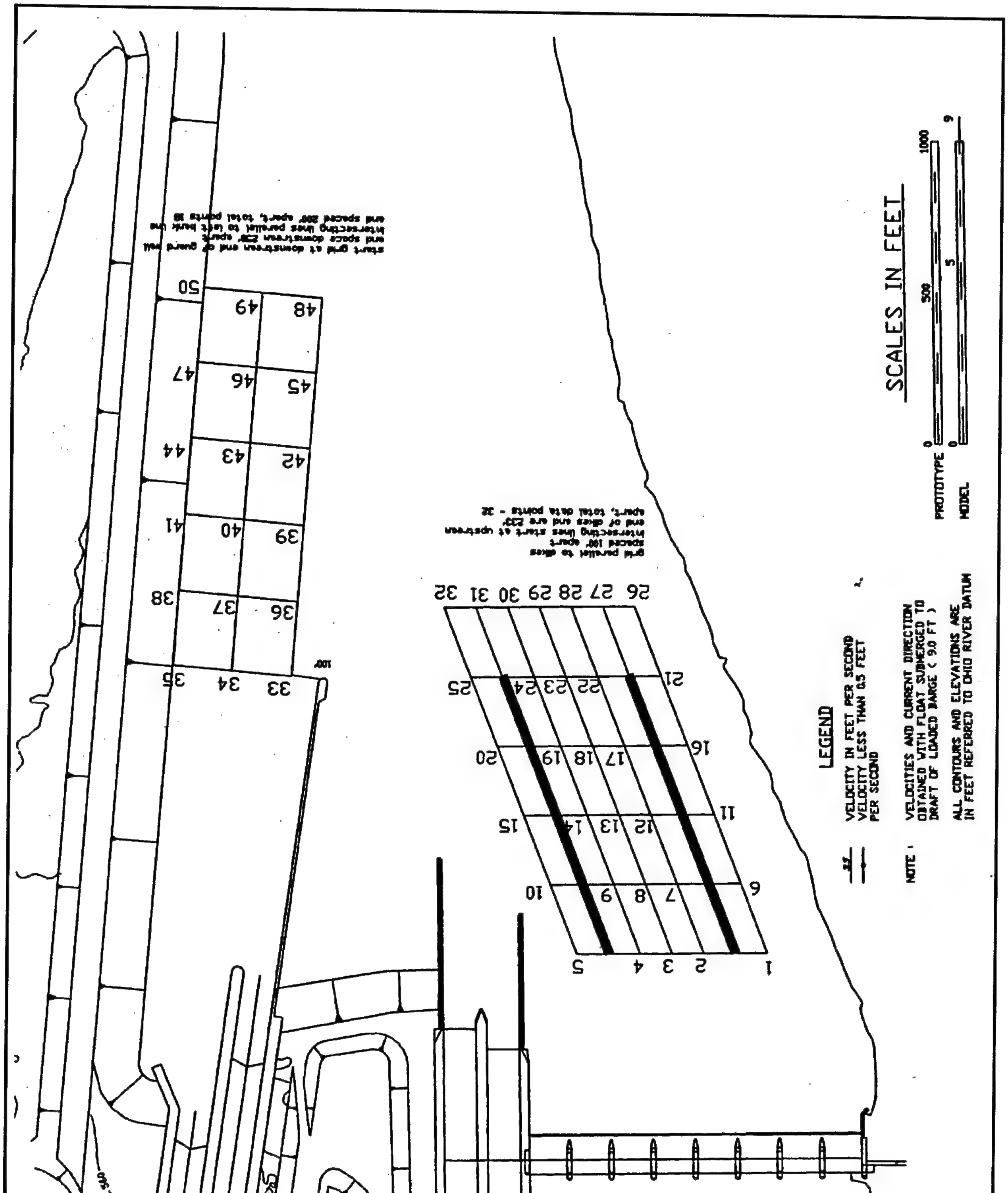


Figure 4. Positions for point velocity data

Table 1
Point Velocity Comparisons, 150,000 cfs

	6/10 Depth; Velocity, fps		8/10 Depth; Velocity, fps	
Pt. No.	**Base**	**Plan A**	**Base**	**Plan A**
1	5.8	4.6	5.7	4.5
2	4.7	4.9	4.5	4.8
3	4.7	5.0	4.5	5.0
4	3.8	4.7	3.8	4.3
5	5.4	5.2	5.0	5.0
6	5.9	5.4	5.8	5.3
7	5.3	5.5	5.4	5.4
8	4.7	5.3	4.6	5.2
9	4.4	5.4	4.7	5.2
10	4.4	5.1	4.2	5.1
11	6.2	5.9	6.2	5.8
12	5.5	6.0	5.5	5.8
13	4.7	5.3	4.7	5.5
14	4.9	5.4	4.8	5.4
15	5.1	5.5	4.8	5.2
16	6.4	6.2	6.3	6.2
17	5.7	6.4	5.7	6.3
18	5.0	5.9	5.0	5.7
19	5.3	5.3	4.9	5.4
20	5.2	5.6	4.9	5.2
21	6.2	6.4	6.0	6.0
22	6.1	5.8	5.7	5.5
23	5.4	5.4	5.0	5.1
24	5.5	4.6	5.2	4.7
25	4.9	5.1	4.6	4.4
26	6.6	6.1	6.2	5.7
27	6.0	3.6	5.7	3.2
28	5.8	5.8	5.3	5.4
29	5.4	5.4	5.2	5.0
30	5.4	4.5	5.2	4.7
31	4.9	3.5	4.9	3.2
32	4.5	4.3	4.1	3.6
33	1.2	1.3	1.0	1.4
34	1.5	1.2	1.5	1.5
35	1.1	0.6	0.8	0.5
36	1.0	1.2	0.8	1.1
37	1.5	1.5	1.4	1.8
38	2.0	2.2	2.1	1.3
39	0.4	0.4	0.3	0.3
40	1.2	1.3	1.2	1.3
41	2.5	2.5	2.8	2.8
42	0.6	0.8	0.7	0.5
43	1.0	1.1	0.9	1.2
44	2.6	2.8	2.6	2.7
45	2.0	1.7	2.2	1.6
46	0.4	0.7	0.7	0.7
47	2.7	2.5	2.7	2.1
48	3.1	3.0	2.9	2.5
49	0.7	1.1	0.5	0.8
50	1.1	1.5	1.7	1.5

Table 2
Point Velocity Comparisons, 300,000 cfs

	6/10 Depth; Velocity, fps		8/10 Depth; Velocity, fps	
Pt. No.	Base	Plan A	Base	Plan A
1	6.1	6.4	6.1	6.3
2	7.5	7.7	7.2	7.5
3	6.6	7.3	6.7	7.1
4	6.2	6.5	6.0	6.2
5	7.7	8.0	7.4	7.3
6	6.1	6.7	6.0	7.2
7	7.0	7.6	7.0	7.7
8	7.6	8.0	7.5	8.0
9	8.1	8.5	7.6	8.2
10	6.3	7.0	6.1	6.8
11	7.0	8.0	6.7	7.6
12	6.9	7.6	6.7	7.4
13	7.1	7.7	7.0	7.5
14	7.5	7.6	7.5	7.7
15	6.7	7.3	6.2	6.8
16	7.5	8.4	7.3	8.3
17	7.7	8.4	7.4	8.0
18	7.5	8.4	7.1	8.2
19	7.3	7.7	7.1	8.0
20	6.3	7.1	5.9	6.8
21	7.7	8.3	7.3	8.2
22	7.9	8.5	7.5	7.9
23	7.9	8.5	7.6	8.0
24	7.4	7.2	6.9	7.2
25	5.6	6.0	5.2	5.3
26	8.0	8.2	7.8	8.1
27	7.9	7.4	7.6	6.5
28	7.9	8.5	7.7	8.3
29	7.9	8.3	7.6	8.2
30	7.4	7.2	6.9	7.0
31	6.4	5.8	6.1	5.1
32	4.4	4.2	4.1	3.9
33	1.6	1.5	1.6	1.3
34	1.2	1.6	0.8	1.5
35	0.5	0.6	0.5	0.9
36	1.2	1.5	1.4	1.3
37	1.3	1.9	1.7	1.5
38	2.6	2.6	2.3	2.6
39	0.4	0.4	0.4	0.4
40	1.2	1.4	1.1	1.5
41	2.8	3.2	3.1	3.0
42	0.6	0.2	0.6	1.5
43	1.2	1.3	1.2	0.4
44	3.1	3.2	3.3	3.6
45	2.0	1.4	2.0	1.1
46	0.8	0.9	0.9	1.2
47	2.9	3.2	2.9	3.3
48	3.8	3.3	3.4	2.9
49	1.1	0.5	0.7	0.6
50	2.2	2.6	2.3	2.6

For the 300,000-cfs flow condition (Table 2), the velocities for Plan A at six-tenths- and eight-tenths-depth were generally higher in and around the dike field than those of the base conditions. The velocities in the lock approach at both the six-tenths- and eight-tenths-depth are generally about the same for the Plan A condition as those of the base conditions.

Dye and Confetti Streak Photographs

Description

Current directions and velocities are obtained by tracking floats that are drafted to 9-ft depth. To obtain a better understanding of how the surface currents and flow through the water column are moving, the patterns of the flow, and how these movements and patterns would be influenced by the introduction of the vane dikes below the dam, photographs were made of the model after the introduction of dye and confetti into the model with both the base and Plan A conditions with the 150,000- and 300,000-cfs flows.

The camera was mounted overhead and along the left bank side of the model and provided a view starting just upstream and riverward of the guard wall to approximately 1,700 ft downstream of the guard wall. Photographs were taken at intervals after introduction of the dye and confetti to show how flow moves into the large eddy in the lock approach and how this flow circulates. Two photos are shown for each plan and flow condition using dye to demonstrate how the flow patterns develop.

Results

Dye photographs. Photographs taken during the 150,000-cfs flow with the base (Photo 1 and 2) and Plan A (Photo 3 and 4) conditions show similar patterns of the eddy development. The flow along the left side of the channel moves down toward the left descending bank line approximately 1,400 ft downstream of the guard wall, then turns and comes directly upstream along the bank line and finally turns across the lock approach as it gets abreast of the end of the guard wall. The basic size and shape of the eddy are almost the same for both the base and Plan A conditions.

Photographs taken during the 300,000-cfs flow with the base (Photo 5 and 6) and Plan A (Photo 7 and 8) conditions show similar patterns of the eddy development. The flow along the left side of the channel moves downstream toward the left bank approximately 1,600-1,800 ft downstream of the end of the guard wall before turning and moving upstream along the left descending bank line. The flow moves upstream until it is abreast or slightly upstream of the end of the guard wall before moving across the lock approaches and going riverward of the end of the guard wall. It can be noted, especially on Photo 5 of the base condition and Photo 7 of the Plan A condition, that counterclockwise rotating vortices have formed and are moving downstream. These vortices develop in the area between the new guard wall and the old guide wall. They start as a small eddy in

this relatively slack water area and as it gains speed, the eddy breaks out and moves downstream continuing to rotate as it moves.

Confetti photographs. Photographs taken during the 150,000-cfs flow with the base (Photo 9) and Plan A (Photo 10) conditions indicate a slight enlargement and strengthening of the downstream portion surface eddy of the Plan A conditions as compared with the base condition. The streaks, about one-third of the photo from the left and about halfway up from the bottom, appear to be moving more toward the left bank with the Plan A condition than those with the base condition. The center of the eddy and the general pattern of movement of the upstream portion of the eddy appear to be similar for both conditions.

Photographs taken during the 300,000-cfs flow with the base (Photo 11) and Plan A (Photo 12) conditions show that the center of the eddy is approximately the same for both conditions and the general pattern of flow in the upstream half of the eddy are similar for both conditions. The eddy appears to be compressed somewhat in width immediately downstream of the center of the eddy for Plan A as compared to the base conditions and the eddy for Plan A appears to extend slightly farther downstream along the left bank. This can be noted by the streaks in the extreme lower left hand corner which show streaks still moving downstream as they go out of the photograph while practically all of the confetti has turned inside the base condition photograph.

Tracer Material Photographs

Description

As discussed previously, a fixed-bed type model cannot be used to quantitatively determine scour or deposition that might be influenced by the addition or modification of structures within the model. The model can, however, be used to indicate patterns of where shoaling might occur, especially in a relatively slack water area such as the eddy formed in the lower lock approach. This is accomplished by introducing a plastic bead tracer material with a specific gravity of approximately 1.1 that cannot float but is sufficiently light enough that the currents will move it along the channel bottom in a manner similar to bed-load material in the prototype.

For this study, a graduated amount of the tracer material was placed in the model during operation of the 150,000- and 300,000-cfs flows with the base and Plan A conditions. After some preliminary evaluation, it was determined that the best position to place this material so that it would be more susceptible to being pulled into the eddy in the lower lock approach was approximately even with and 100 ft riverward of the old guard wall. The material was introduced and allowed to move as the currents took it until all of the material had moved downstream and past the lock approach or into the lock approach. At that time, a series of photographs were made to show where the material had deposited. The amount of time allowed from the introduction of the material until the photographs were made was the same for both the base conditions and Plan A. The tracer material is small white plastic beads. These beads will appear as small white spots when

scattered thinly and as a white patch when they congregate in one spot. The material could not be seen in a wider angle view such as those of the confetti and dye photographs, so a series of closer photographs were made that covered from the downstream end of the guard wall to the left descending bank line approximately 2,500 ft downstream of the end of the guard wall. The approximate coverage for each photo and the relative position of the photo within the model is shown in Figure 5.

Results

150,000 cfs. At photo position 1 (Photo 13 and 14), it appears that more material has moved downstream and closer to the approach to the locks over the same amount of time for Plan A (Photo 14) as compared to the base conditions (Photo 13). At photo position 2 (Photo 15 and 16) the amount of material deposited and the distribution of this material appear to be about equal for both the base conditions (Photo 15) and Plan A (Photo 16). At photo position 3 (Photo 17 and 18), there is a considerably larger amount of material out in the channel for Plan A (Photo 18) than for the base conditions (Photo 17), but the amount and distribution of the material in the lower half of the photo that would be in the lock approach appears to be about equal for the base conditions and Plan A. At photo position 4 (Photo 19 and 20)), there is a much larger amount of material out in the channel for Plan A (Photo 20) as compared with the base conditions (Photo 19). The distributions and concentration of material near the left bank appears to be slightly greater for Plan A than with the base conditions. This may be partially due to the fact that material moved away from the introduction point much faster with the Plan A condition and more material had passed through the model to the area shown in photo position 4 than had passed with the base conditions during the same amount of time.

300,000 cfs. At photo position 1 (Photo 21 and 22), a much larger portion of material introduced into the model was caught in the eddy and deposited in the area between the new guard wall and the old guide wall with the Plan A condition (Photo 22) than with the base conditions (Photo 21). There were only very few of the beads that moved landward toward the left bank for either of the conditions. At photo position 2 (Photo 23 and 24) there is slightly more deposition along the roughly horizontal line on the photos that marks the channelward edge of the lock approach with Plan A (Photo 24) than with the base conditions (Photo 23) but little deposition within the lock approach for either Plan A or the base conditions. At photo position 3 (Photo 25 and 26), there is a considerably larger amount of material riverward of the roughly horizontal line on the photos that marks the channelward edge of the channel for Plan A (Photo 26) than for the base conditions (Photo 25), but the amount and distribution of the material in the lower half of the photo shows less material deposited inside the channel approach for the Plan A condition than with the base conditions. At photo position 4 (Photo 27 and 28), there is a much larger amount of material out in the channel for Plan A (Photo 28) as compared with the base conditions (Photo 27) but considerably more deposition toward the left bank with the base conditions as compared to Plan A.

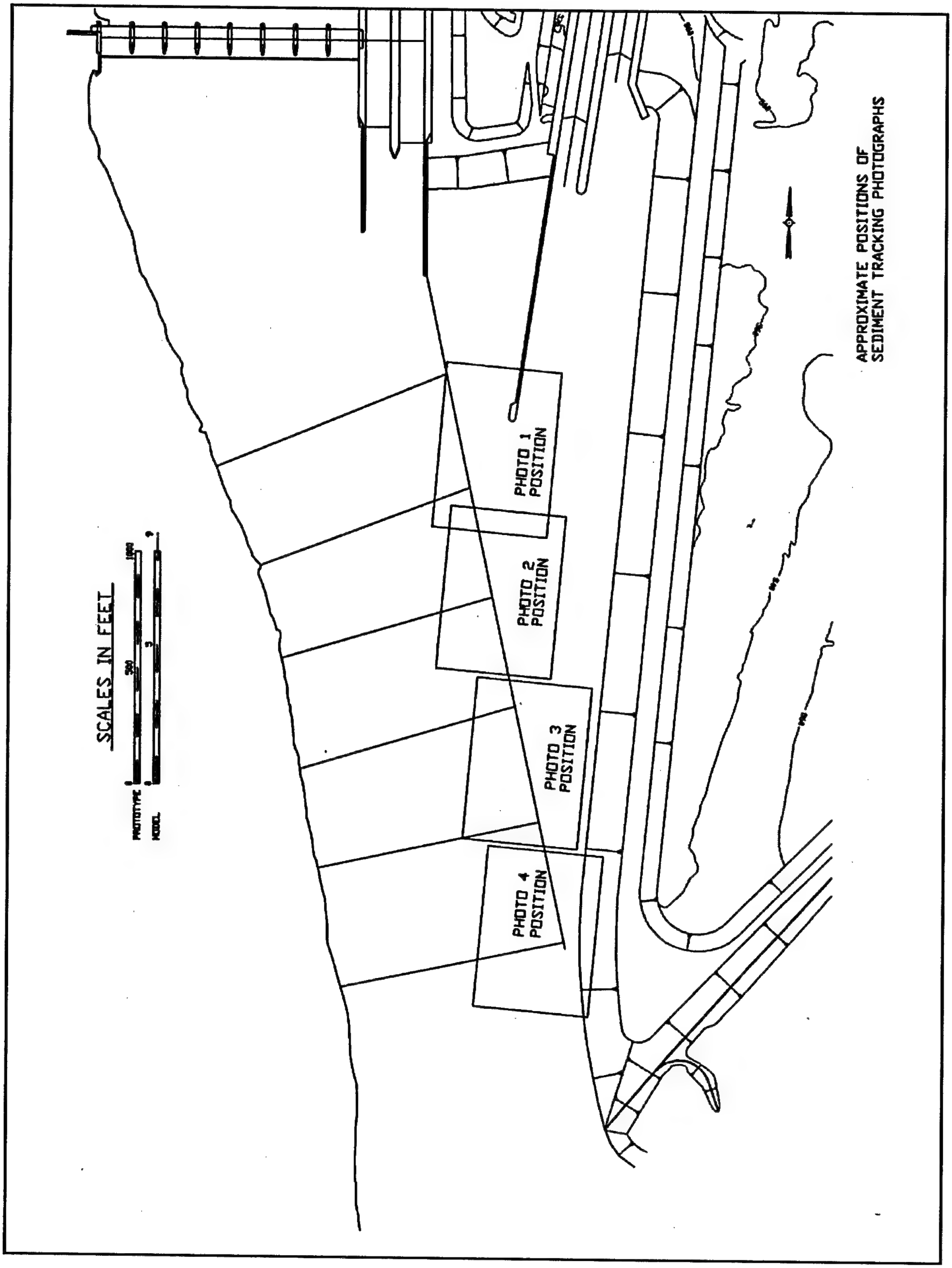


Figure 5. Tracer material photo positions

Plan A-1 Conditions

Description

After completion of evaluations for Plan A, a meeting was held between representatives of the Huntington District and ERDC to discuss the results. During these meetings a question was asked if an increase to the surface area of the dikes would be beneficial for environmental purposes. It was stated that a larger surface area would provide increased habitat and would therefore be beneficial. A suggestion was made that instead of building a 1,000-ft continuous dike that the length be broken into three, 300-ft dikes with a 50-ft spacing between each of the segments. To determine if the change in the design of the dikes might have any effect on navigation conditions in the downstream lock approaches, the modified dike design for Plan A-1 (Figure 6) was installed in the model and current directions and velocities were obtained with the four flow conditions used for previous testing. The current directions and velocities obtained with Plan A-1 were then compared to those obtained with Plan A to determine if there were sufficient changes that would warrant evaluation of navigation conditions with the model towboat.

Results, current directions and velocities

Comparisons of the current directions and velocities taken with Plan A-1 (Plates 43-46) to those taken with Plan A (Plates 23-26) indicate no significant differences in the general velocities or current directions with Plan A-1.

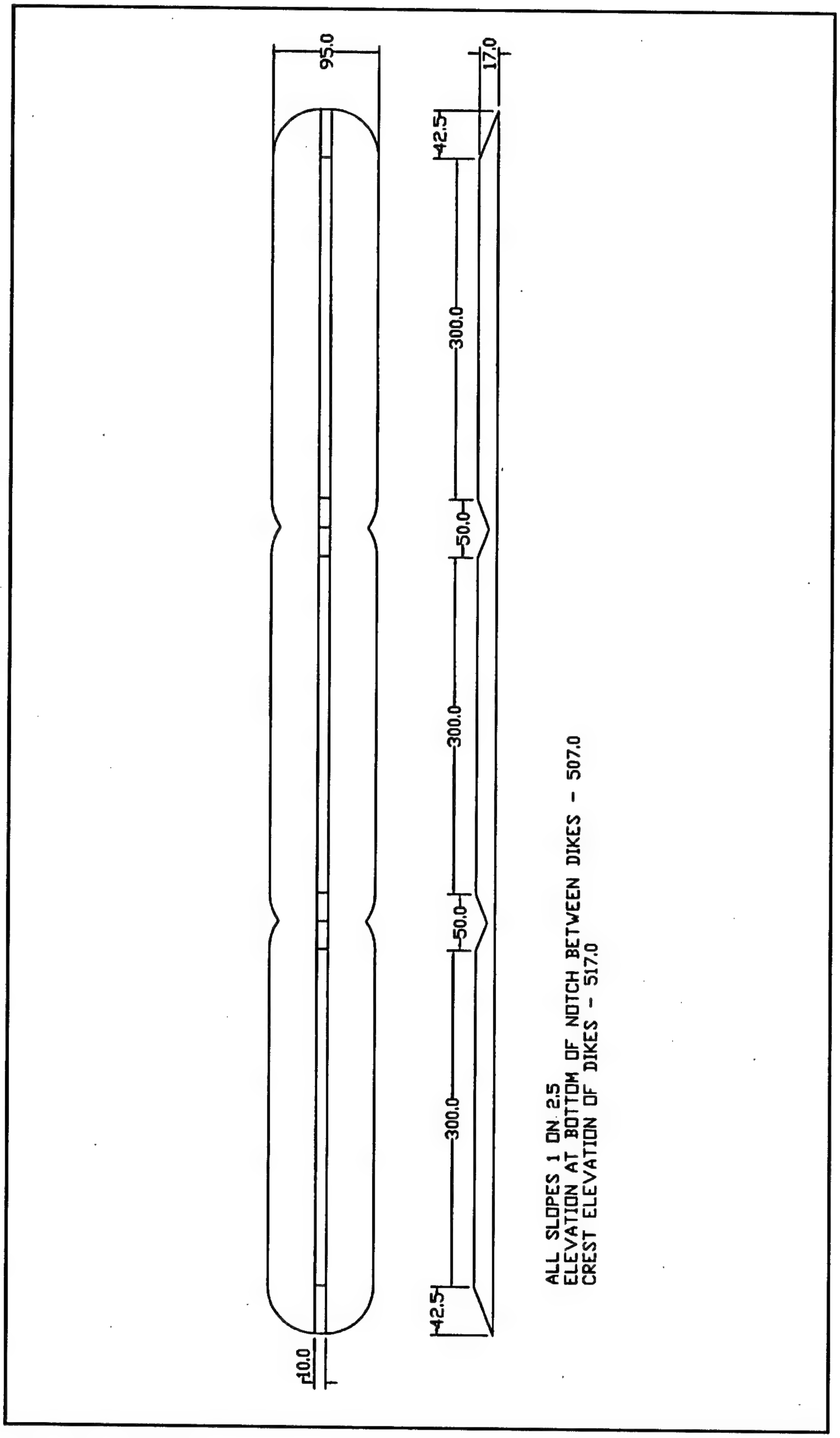


Figure 6. Modified dike design

3 Conclusions

Limitations of Study

Because the model is of the fixed-bed type, changes to the channel bathymetry could not be made without extensive revision. The channel bathymetry in the model is that used for studies performed to study the replacement of the old locks in the early 1970s, which is stated in the report to be 1965. The bathymetry that presently exists at the site could not be placed into the model without major reconstruction. Present navigation conditions may be somewhat different in the prototype as compared to what the model indicates if the channel bathymetry has changed, but these changes, if they exist, are probably relatively small.

Because scour and deposition patterns around the proposed dikes could not be anticipated, the dikes were built directly on the existing channel bathymetry. If these dikes change the scour rate and thereby change the channel bathymetry, this could also affect the current patterns and navigation conditions in the prototype as compared to model results.

Conclusions

Conclusions reached during this model study were as follows:

a. Current directions and velocities did not indicate any significant changes in the lower lock approach for Plan A.

b. Tow tracks did not indicate any significant impact on navigation conditions due to the installation of the Plan A dikes.

c. Point velocities obtained in and around the dike field and in the lock approach indicate that there will be an increase in velocities in the dike field of up to 10 percent with the Plan A dikes but there is very little impact on the velocities in the lock approach with the dikes in place.

d. The dye photographs indicate that the general patterns of current movement in the water column are not appreciably changed with installation of the Plan A dikes.

e. The confetti photographs indicate that the general patterns of surface currents are not appreciably changed with installation of the Plan A dikes.

f. The photographs taken after placement of the plastic tracer material indicate that shoaling tendencies in the lock approach will not be significantly impacted by installation of the Plan A dikes.

g. The use of segmented dikes as evaluated for Plan A-1 will have no greater impacts on navigation than noted for Plan A.

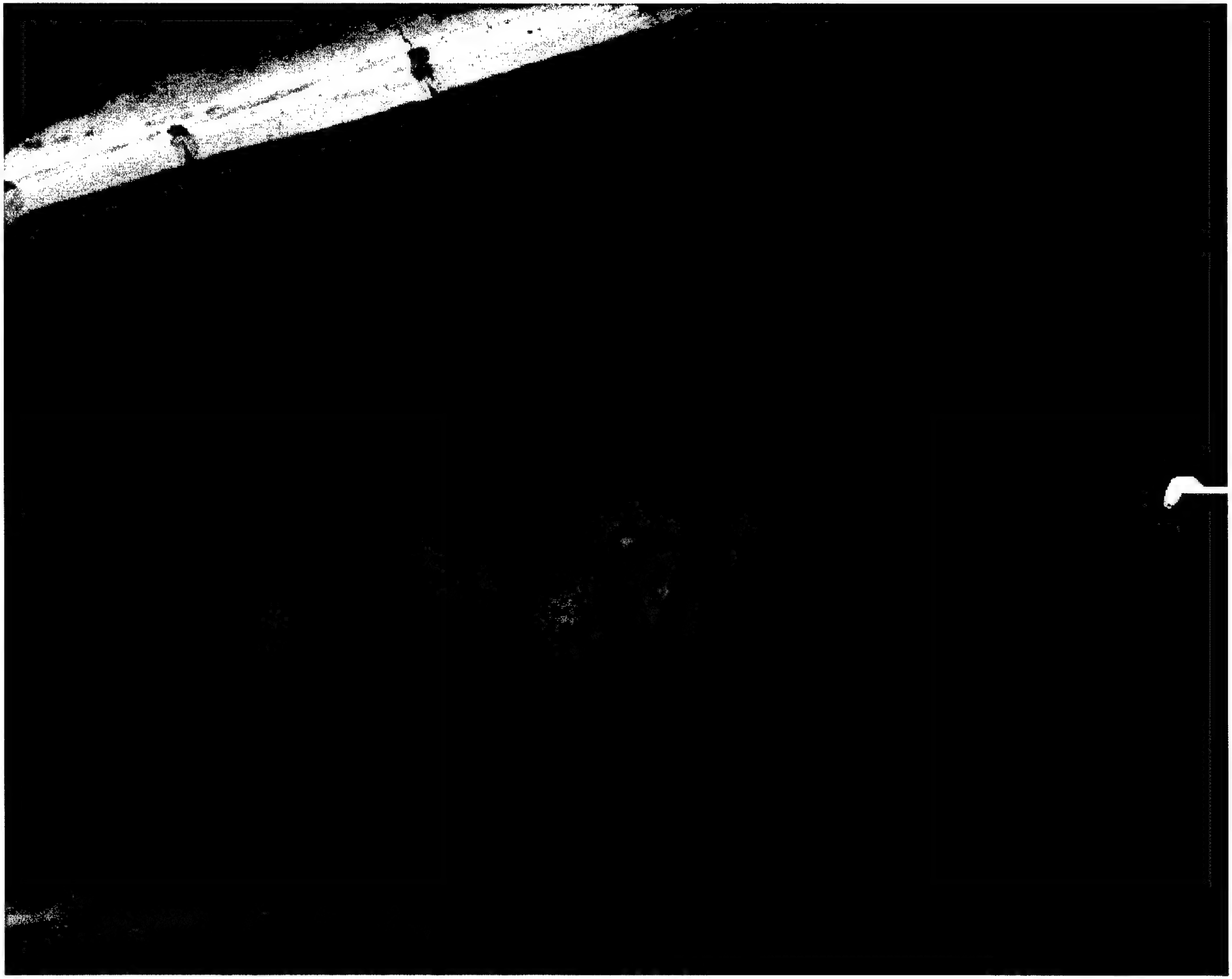


Photo 1. Dye pattern, base condition, 150,000 cfs, early in release

Photo 4. Dye pattern, Plan A condition, 150,000 cfs, late in release

Photo 5. Dye pattern, base condition, 300,000 cfs, early in release

Photo 6. Dye pattern, base condition, 300,000 cfs, late in release

Photo 7. Dye pattern, Plan A condition, 300,000 cfs, early in release

Photo 8. Dye pattern, Plan A condition, 300,000 cfs, late in release

Photo 9. Confetti pattern, base condition, 150,000 cfs

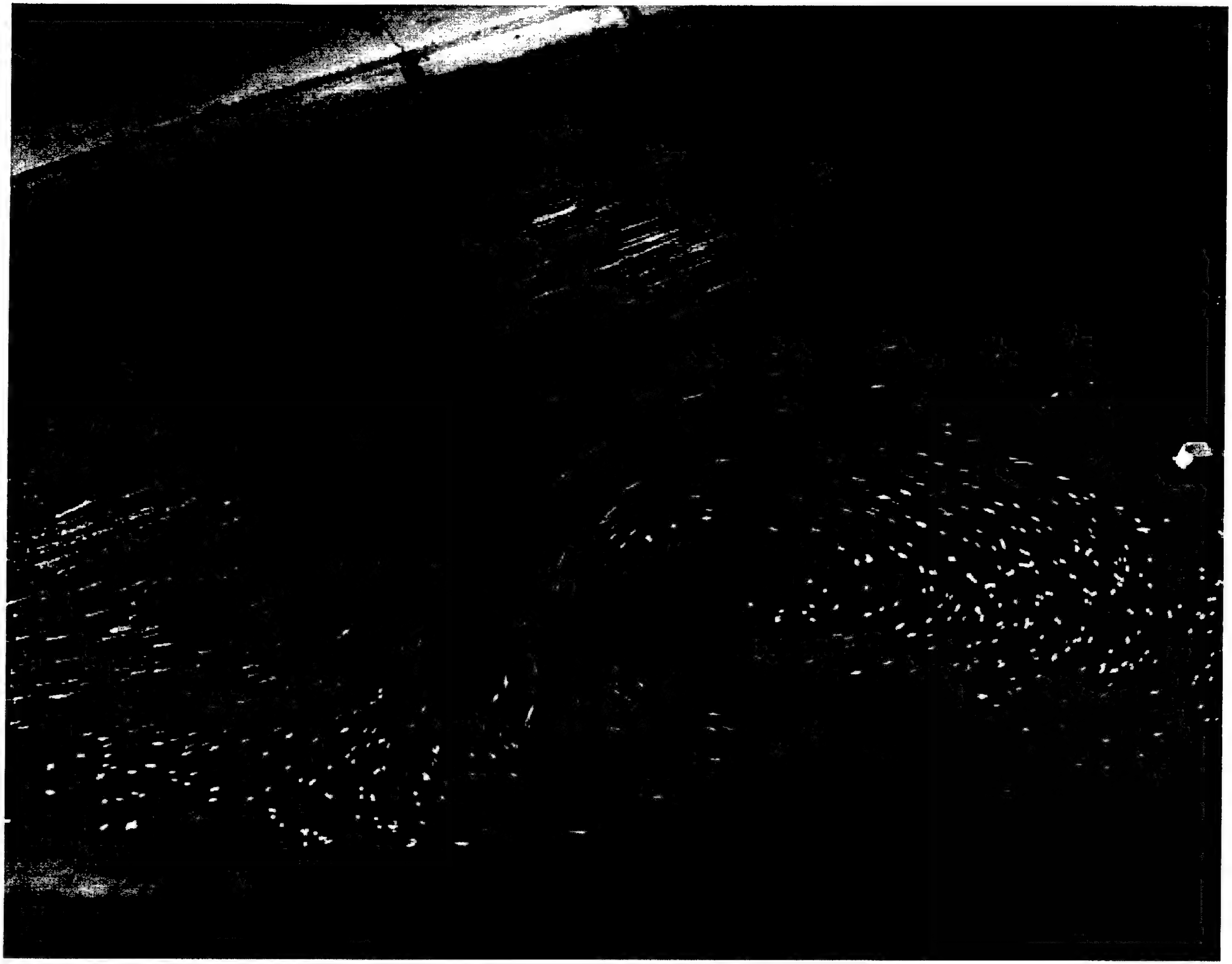


Photo 10. Confetti pattern, Plan A condition, 150,000 cfs

Photo 11. Confetti pattern, base condition, 300,000 cfs

Photo 12. Confetti pattern, Plan A condition, 150,000 cfs, position 1

Photo 13. Tracer beads, base condition, 150,000 cfs, position 1

Photo 14. Tracer beads, Plan A conditions, 150,000 cfs, position 1

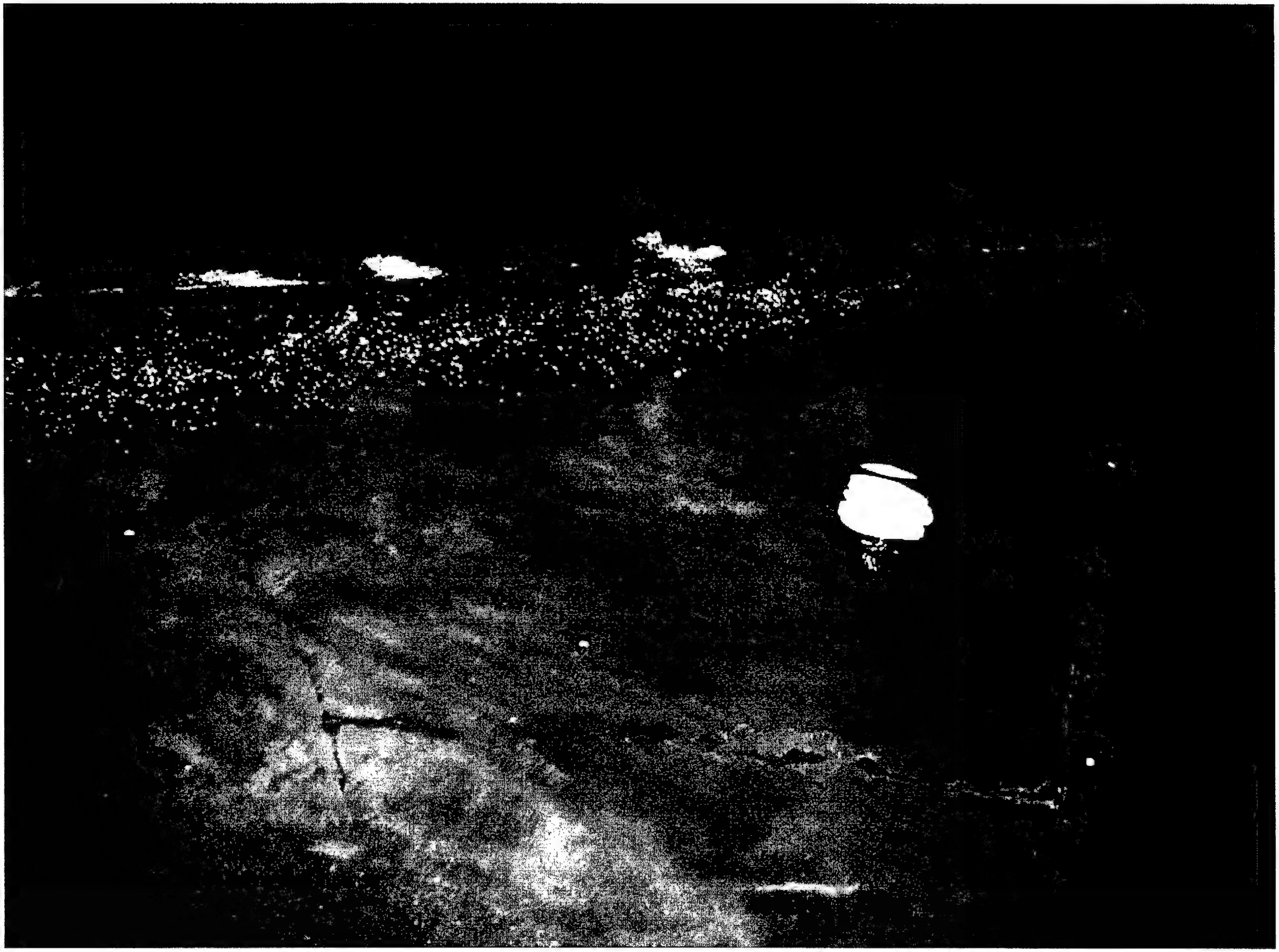


Photo 15. Tracer beads, base condition, 150,000 cfs, position 2

Photo 16. Tracer beads, Plan A conditions, 150,000 cfs, position 2

Photo 17. Tracer beads, base condition, 150,000 cfs, position 3

Photo 18. Tracer beads, Plan A conditions, 150,000 cfs, position 3

Photo 19. Tracer beads, base condition, 150,000 cfs, position 4

Photo 20. Tracer beads, Plan A conditions, 150,000 cfs, position 4

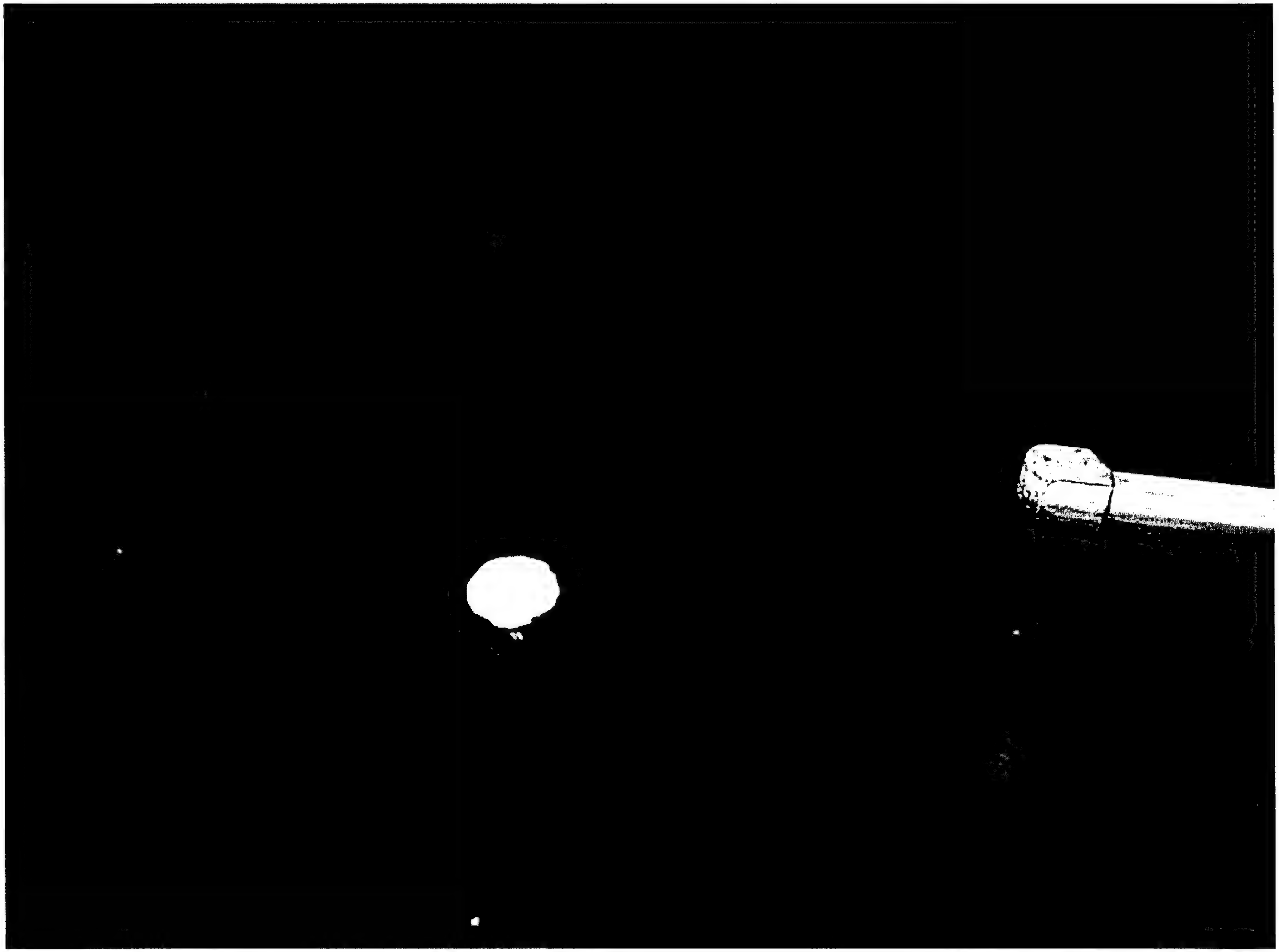


Photo 21. Tracer beads, base condition, 300,000 cfs, position 1

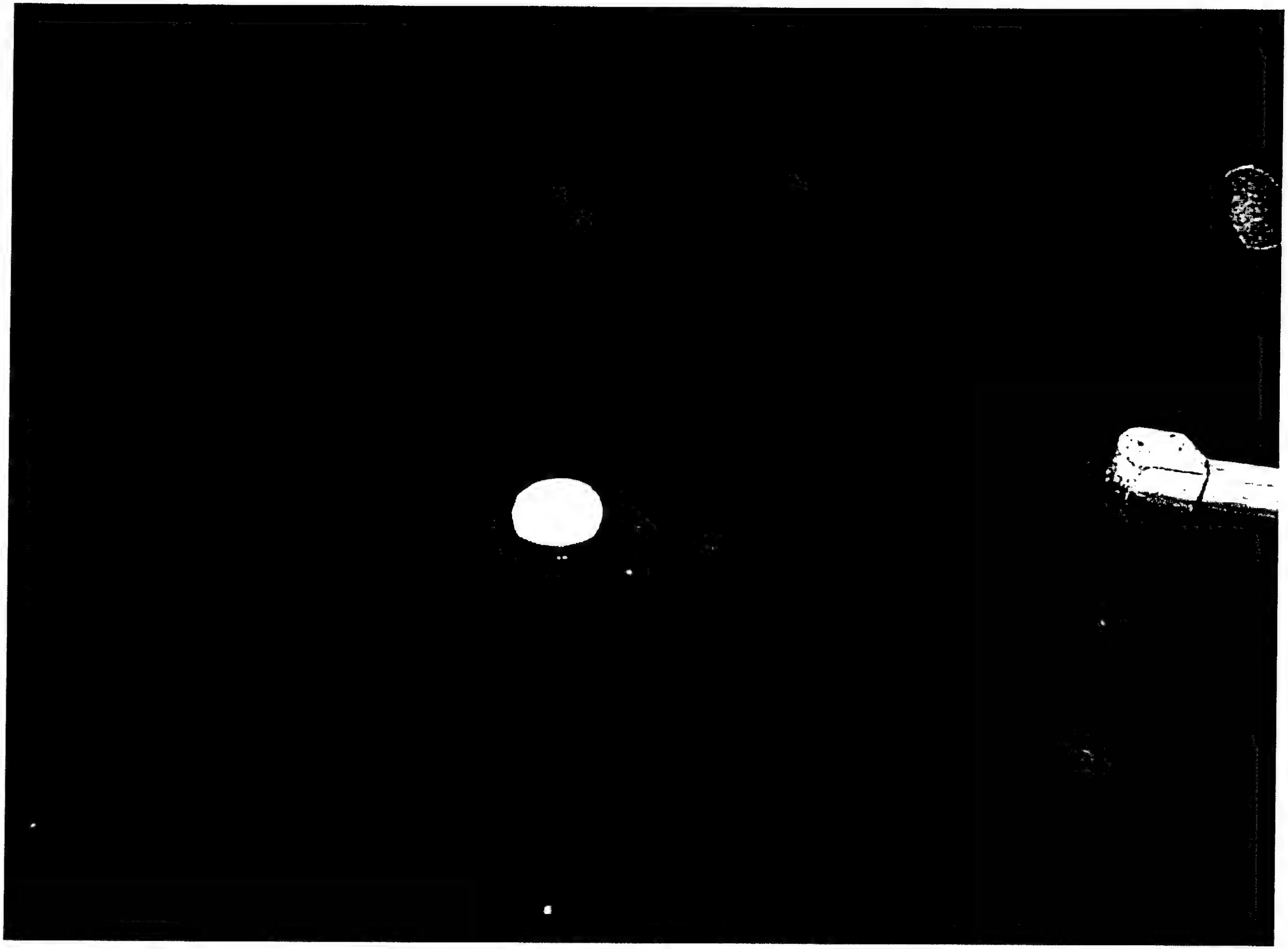


Photo 22. Tracer beads, Plan A conditions, 3000,000 cfs, position 1

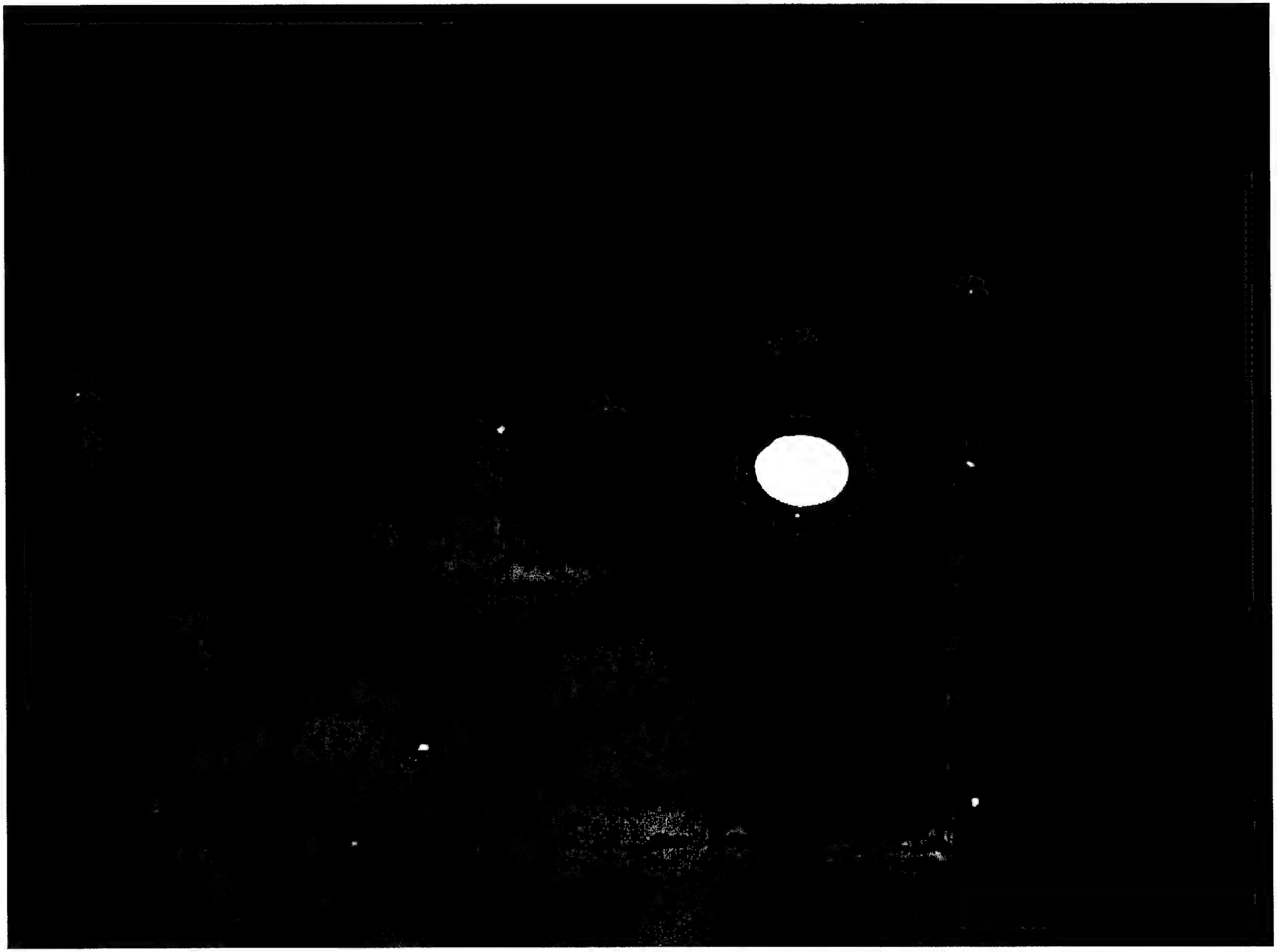


Photo 23. Tracer beads, base condition, 300,000 cfs, position 2

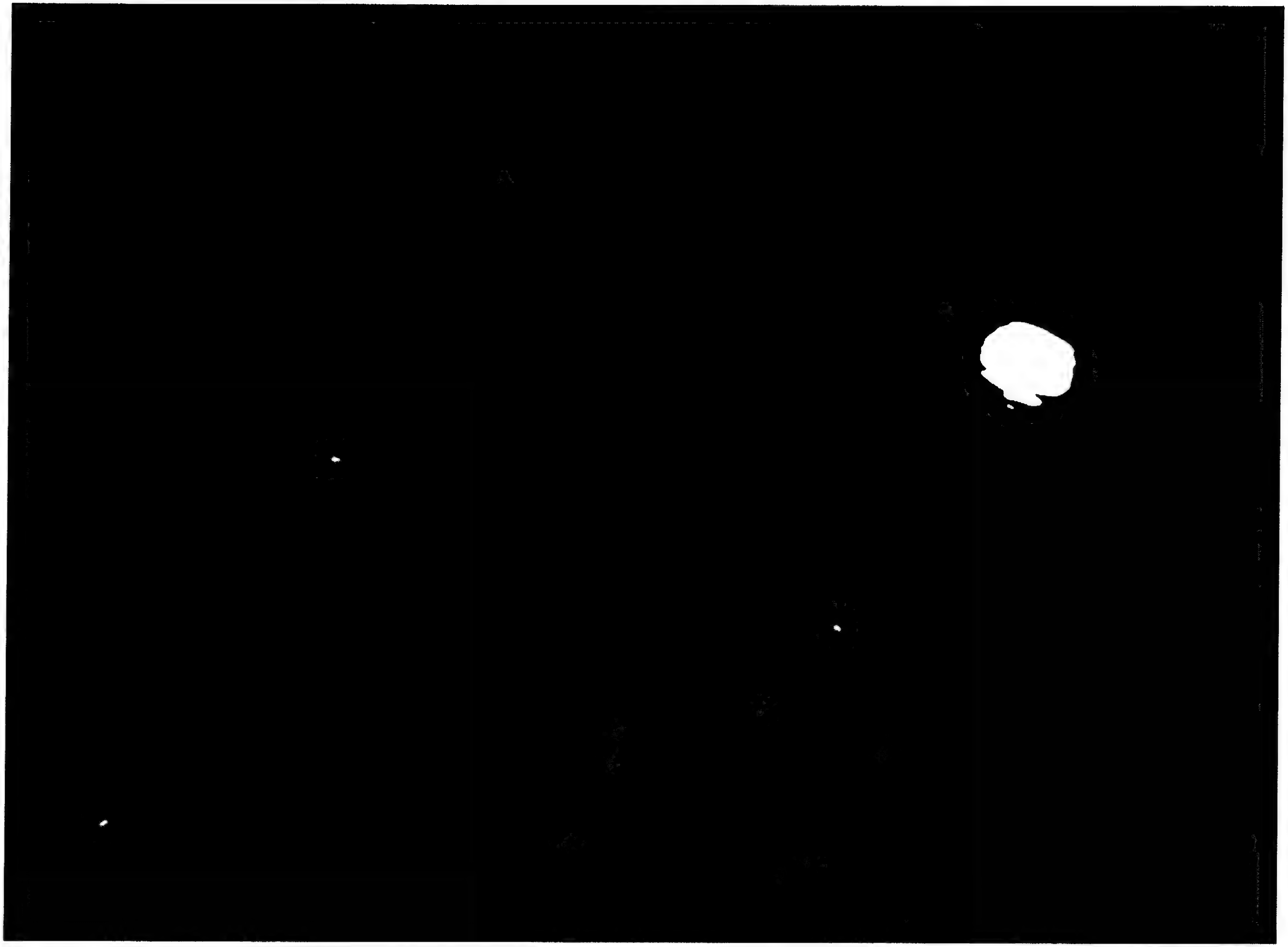


Photo 24. Tracer beads, Plan A conditions, 300,000 cfs, position 2

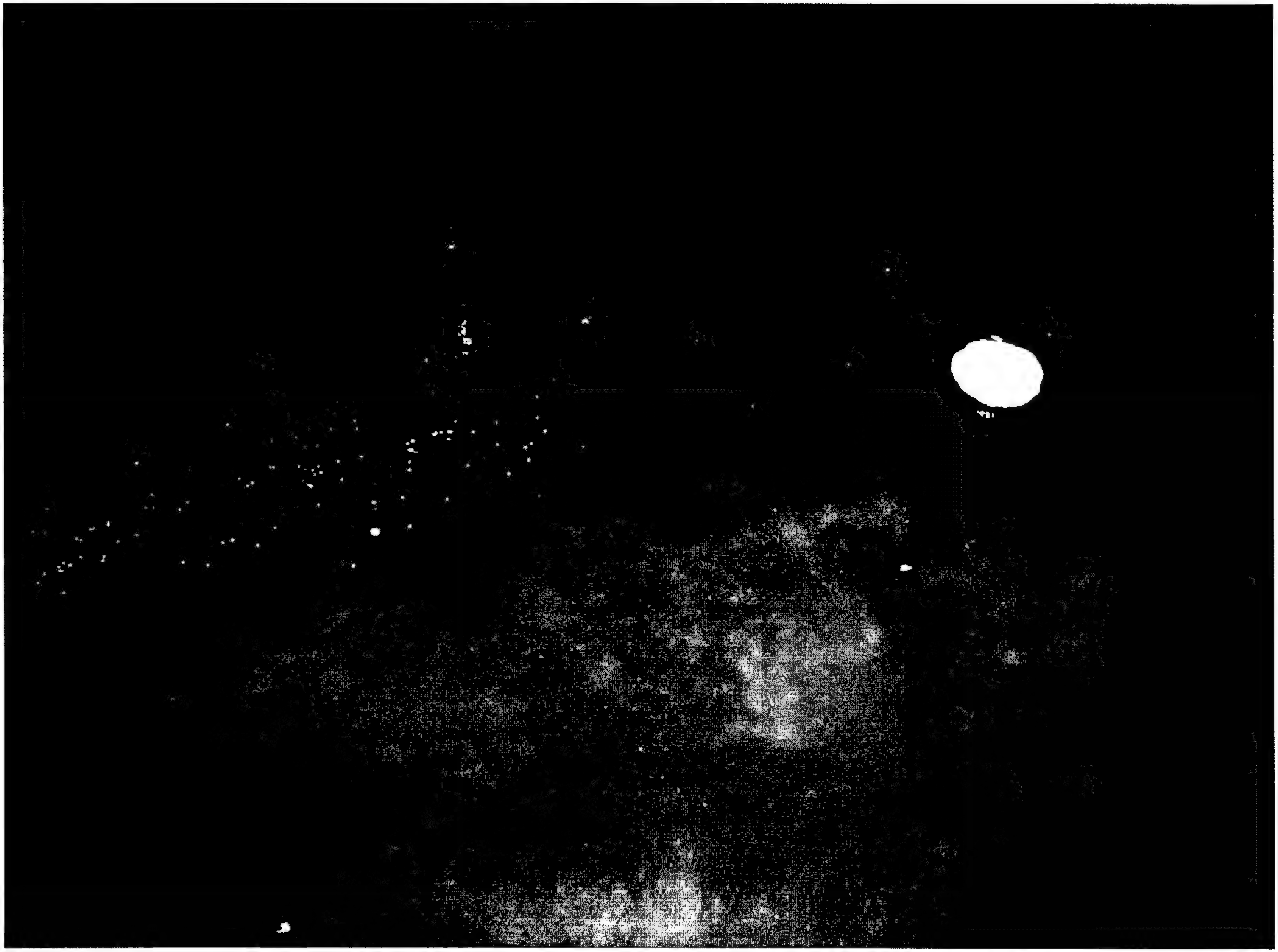


Photo 25. Tracer beads, base condition, 300,000 cfs, position 3

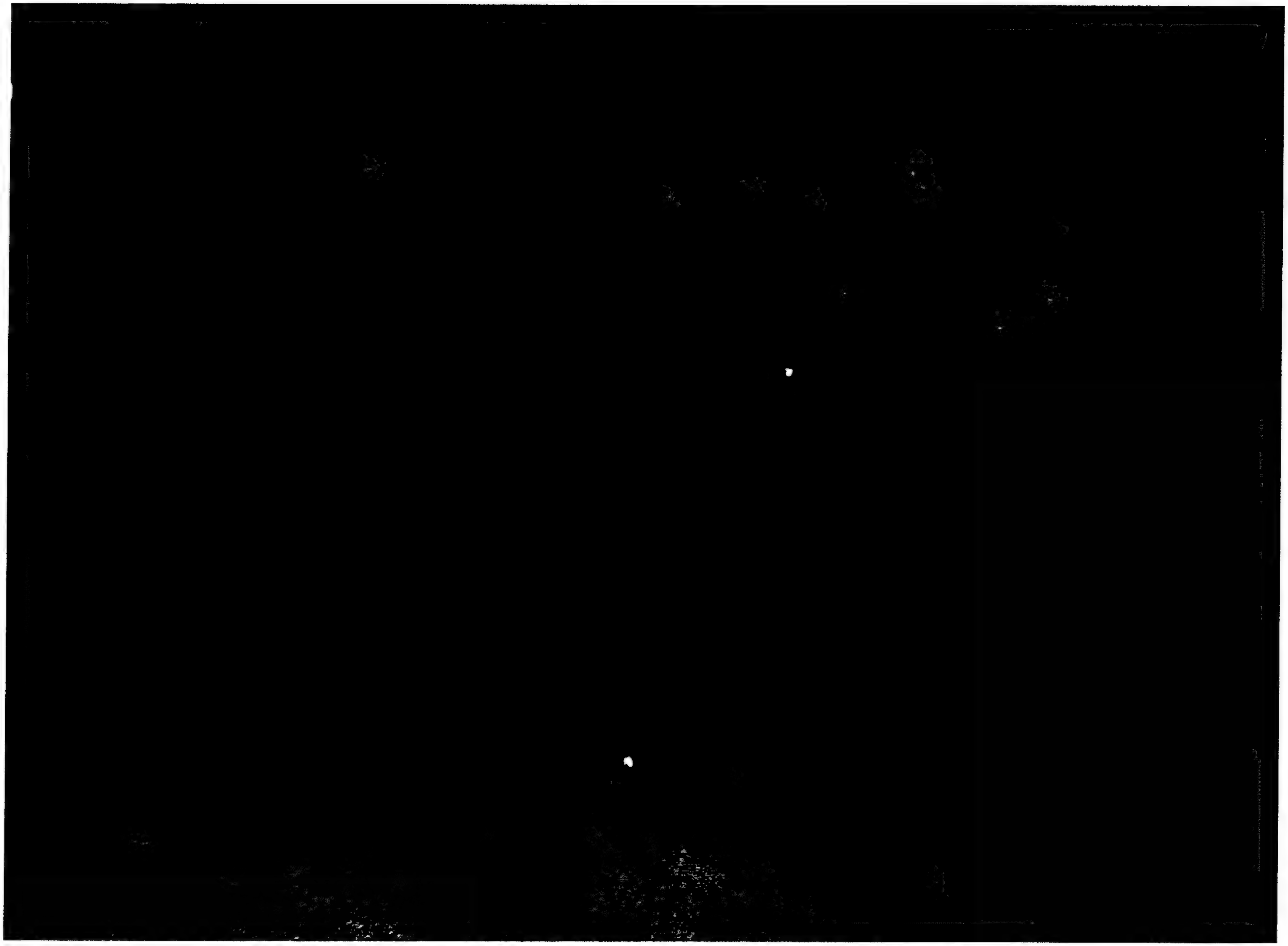


Photo 26. Tracer beads, Plan A conditions, 300,000 cfs, position 3

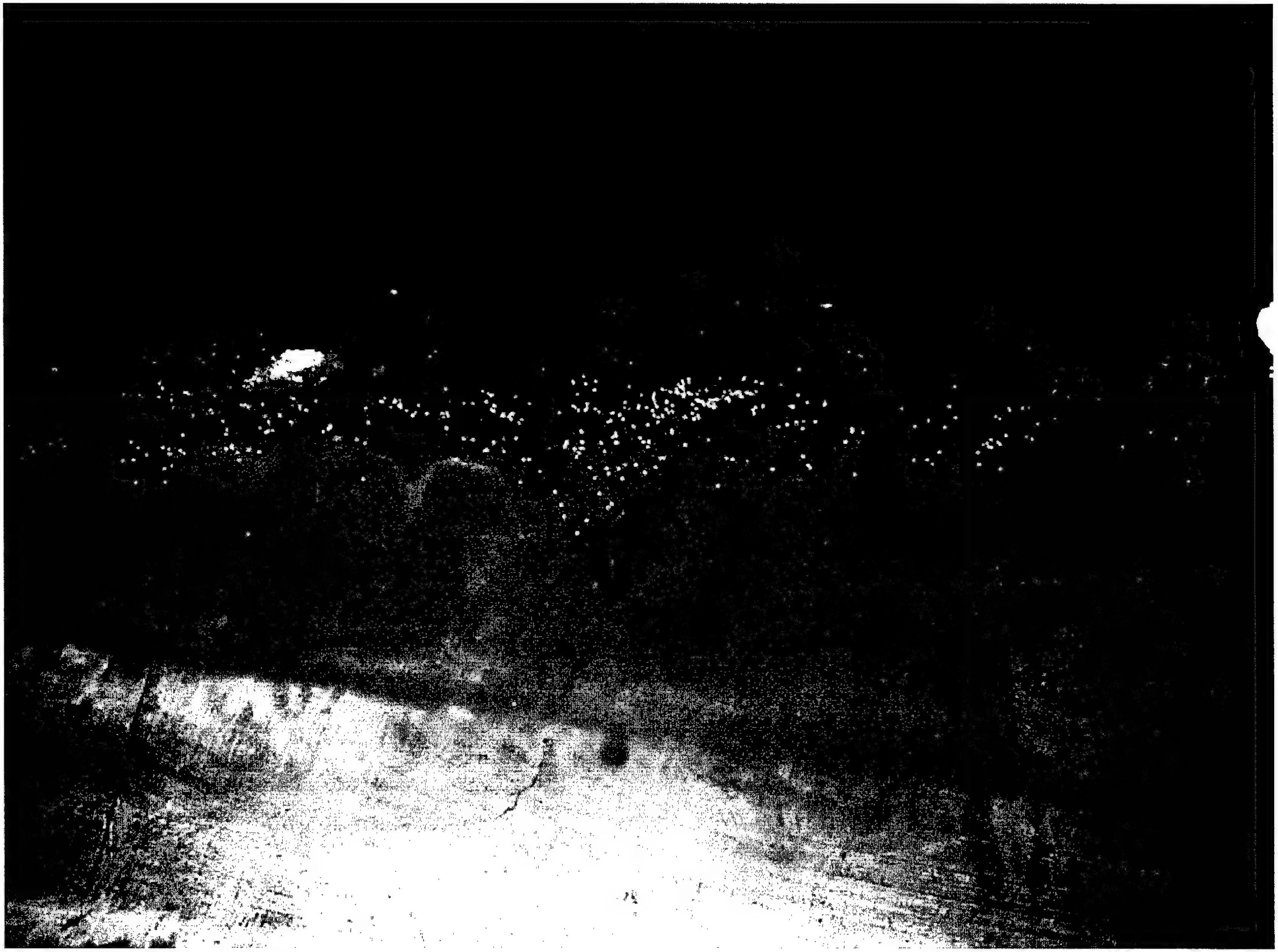


Photo 27. Tracer beads, base A condition, 300,000 cfs, position 4

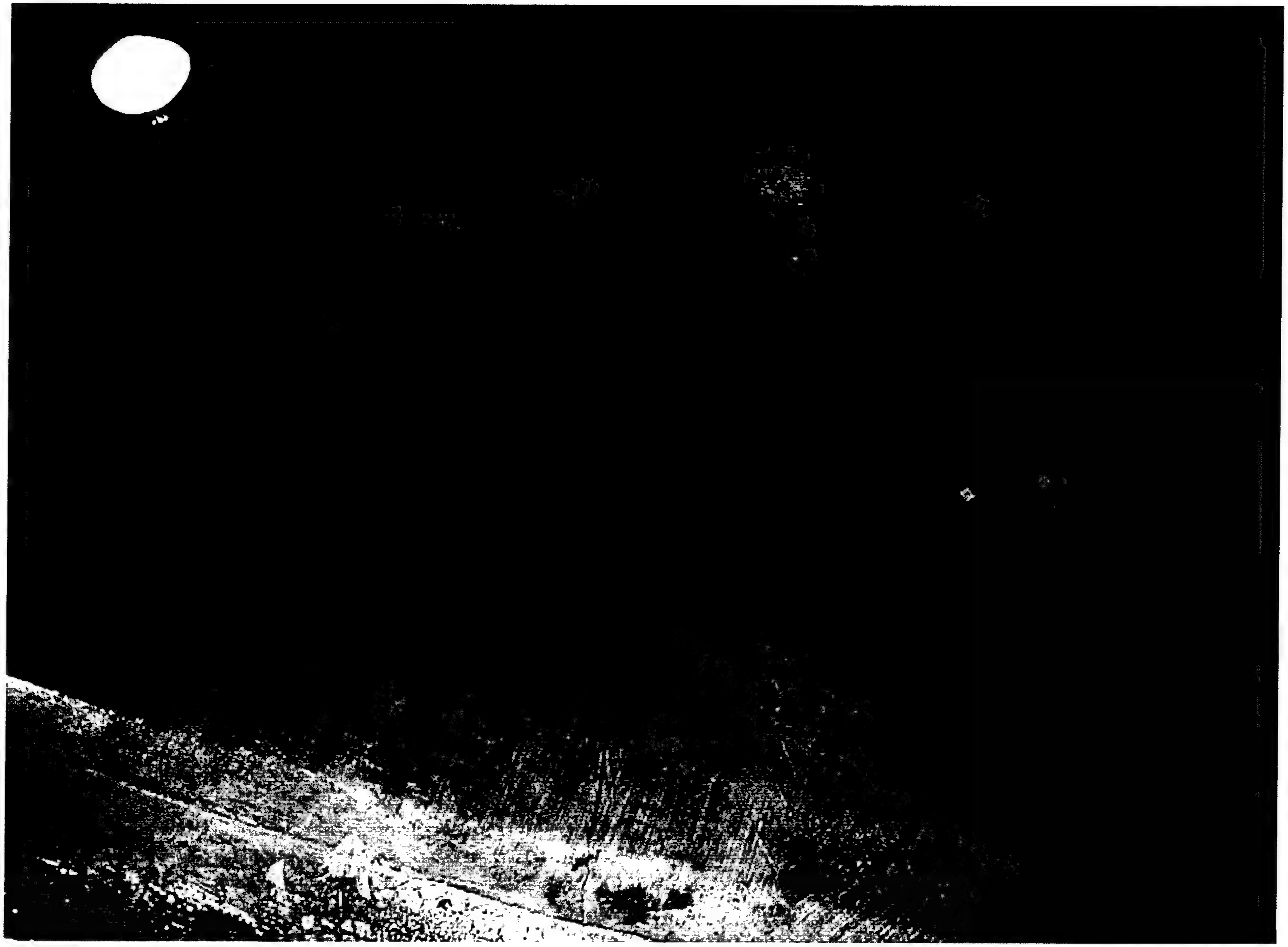


Photo 28. Tracer beads, Plan A conditions, 300,000 cfs, position 4

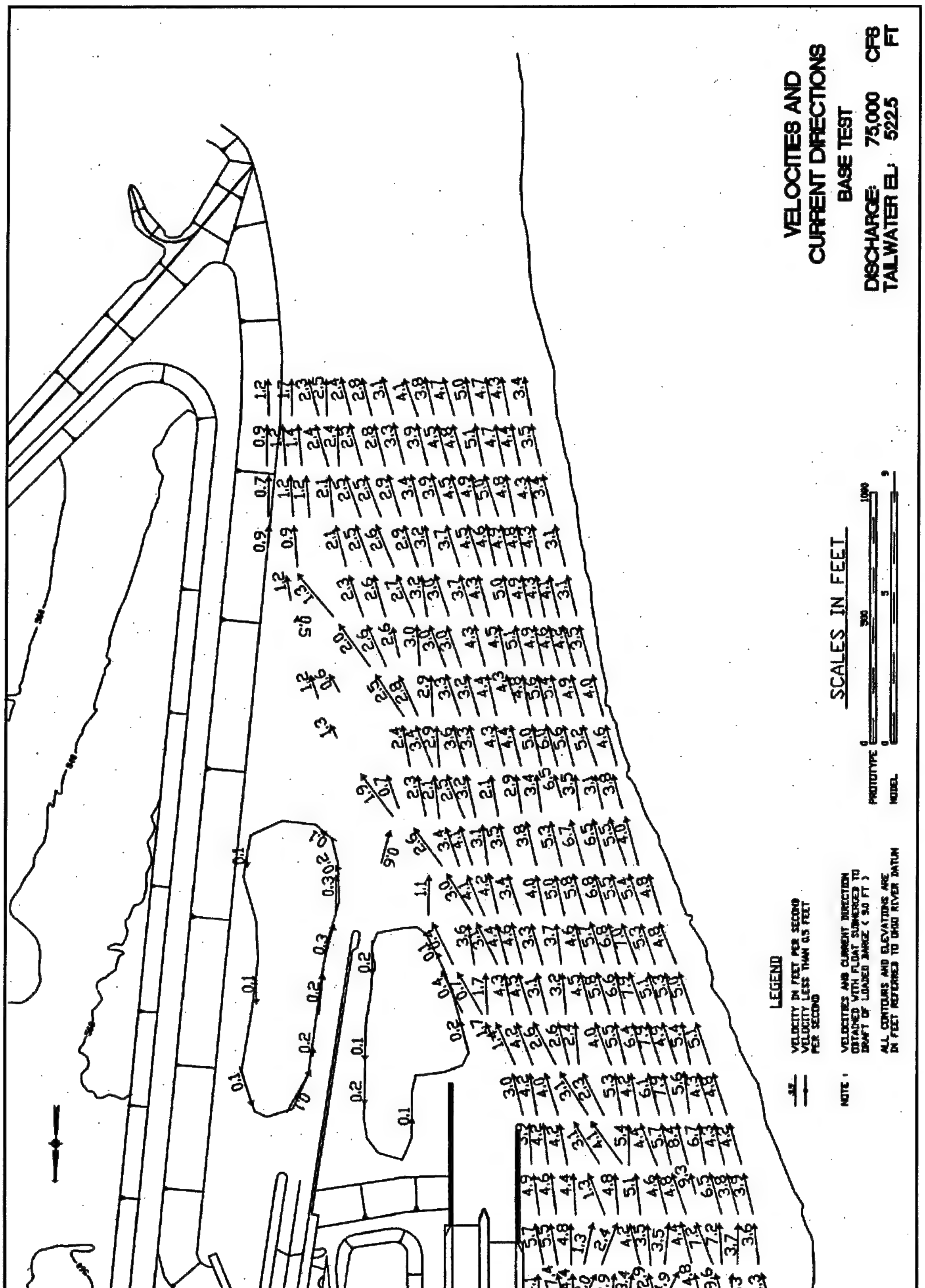

VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 75,000 CFS
TAILWATER EL. 522.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 1

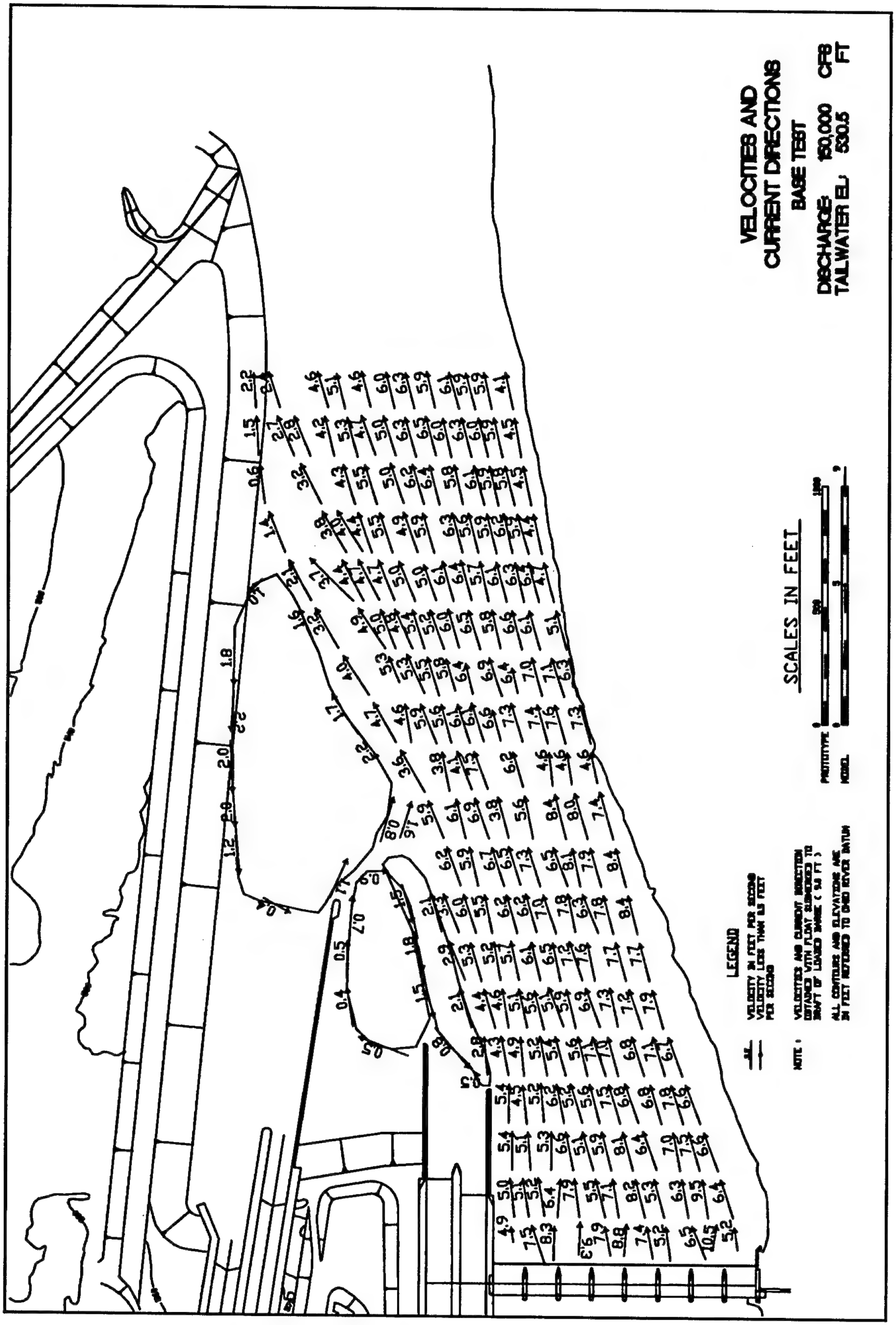
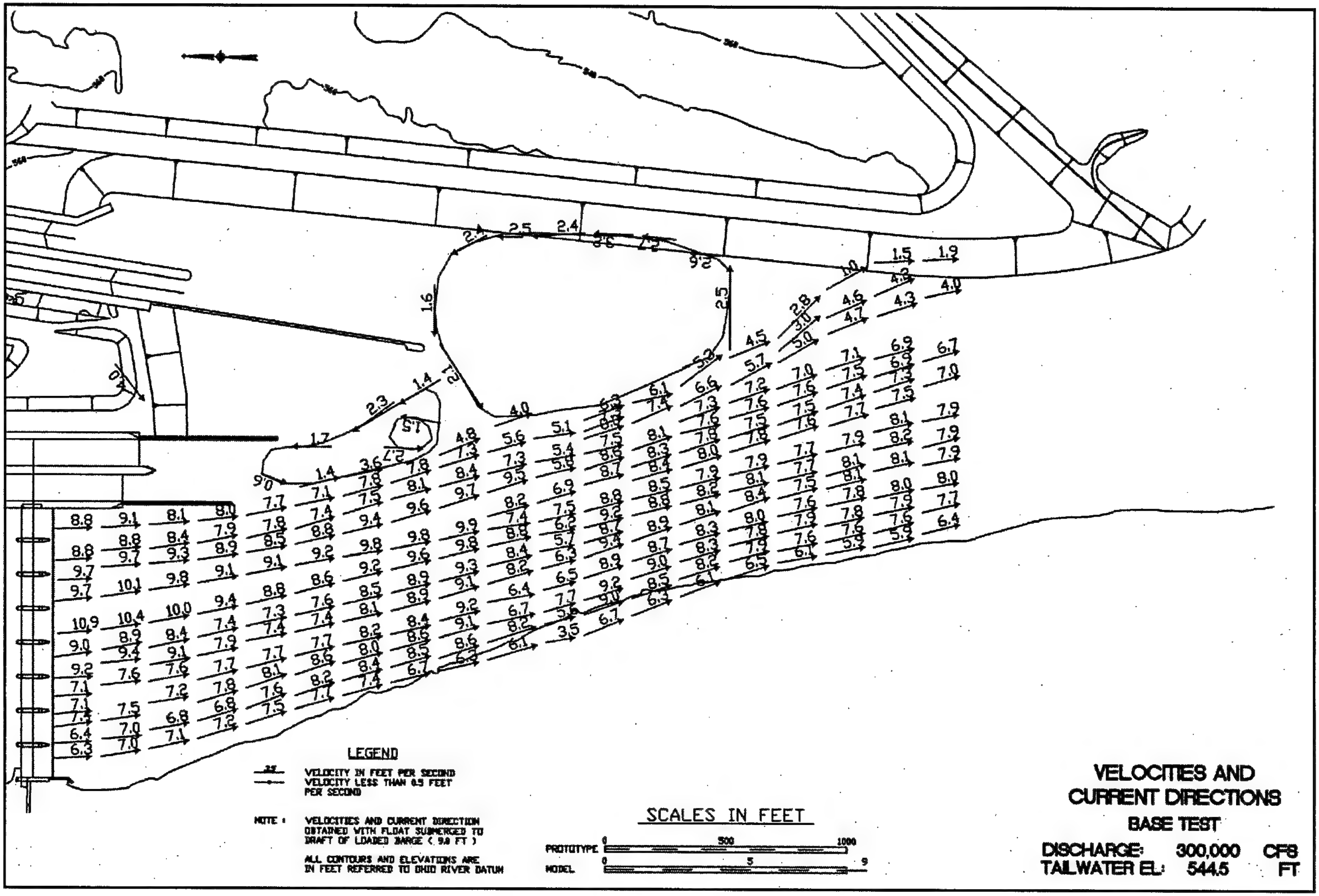
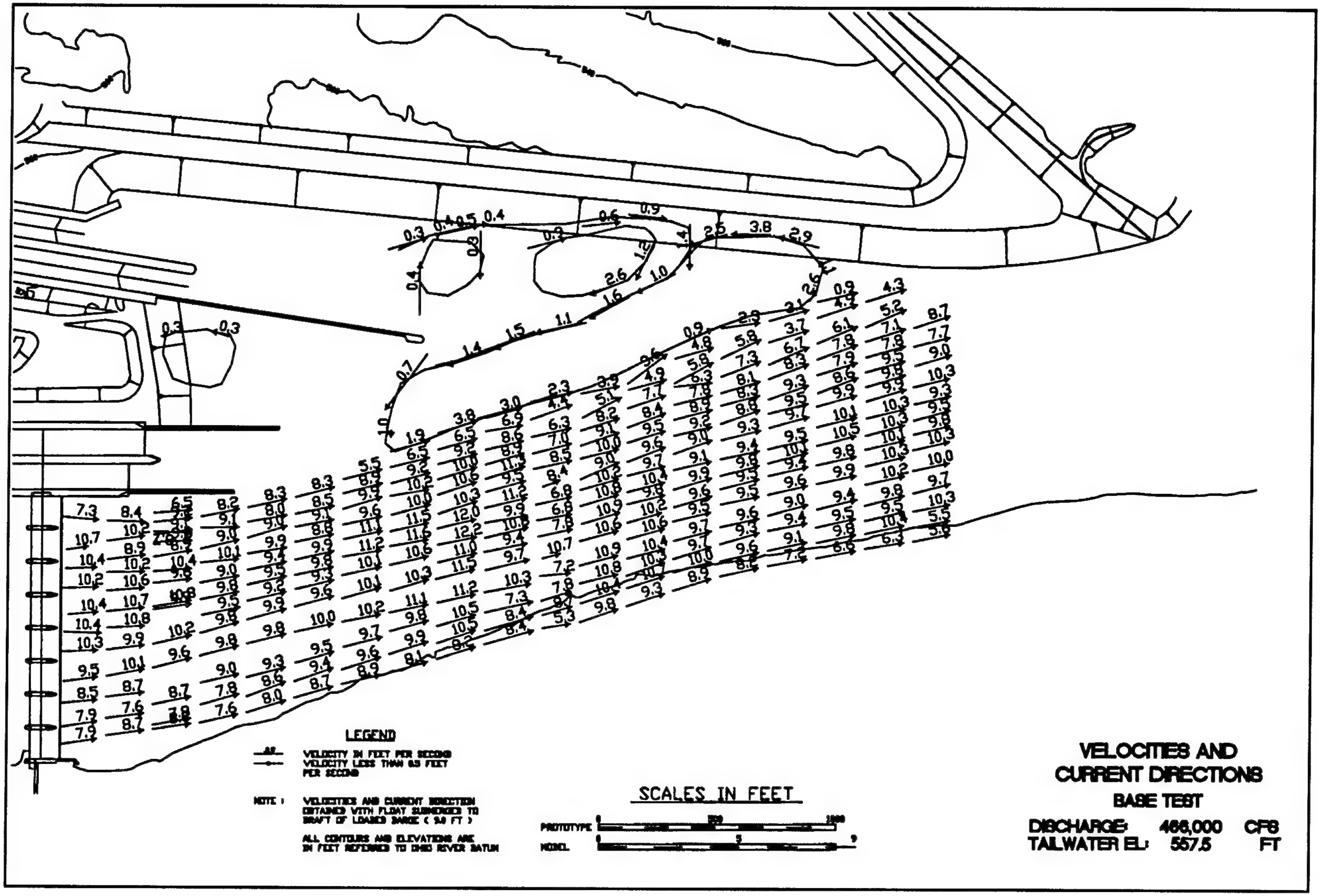

VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
NOTE:
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM

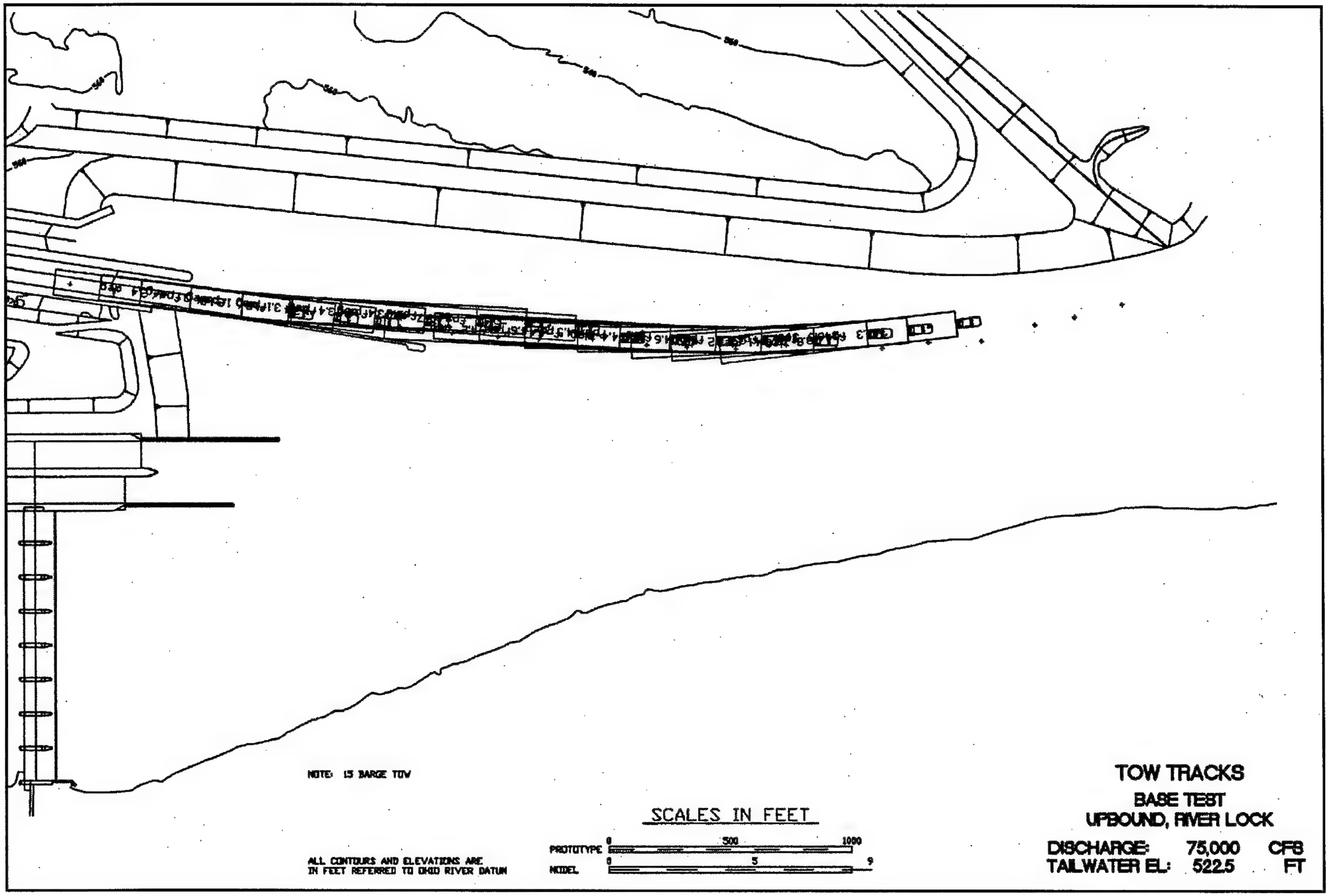
Plate 2


LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.5 FT



LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE
MODEL
VELOCITIES AND CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT

Plate 4


NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
TOW TRACKS
BASE TEST
UPBOUND, RIVER LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT

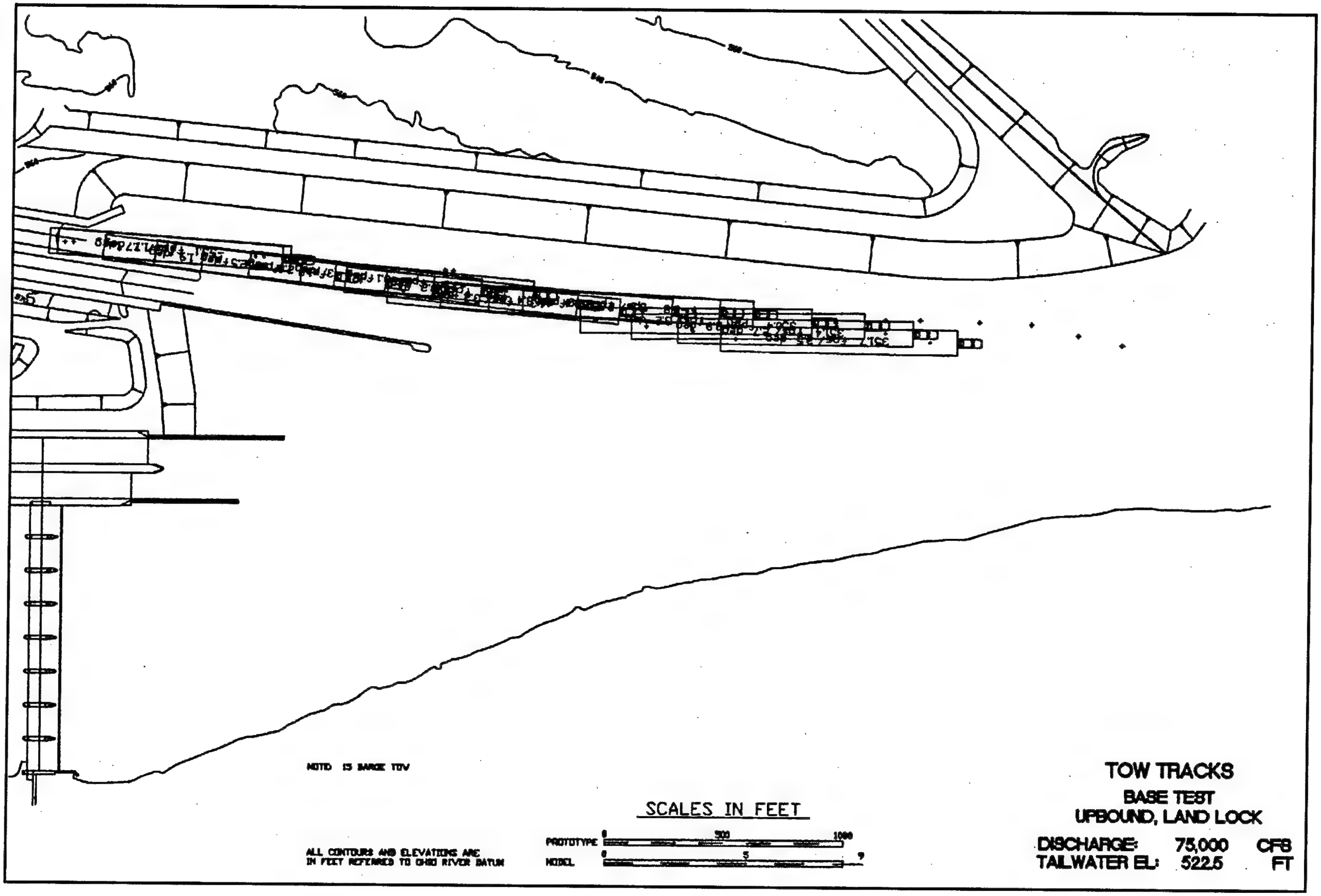
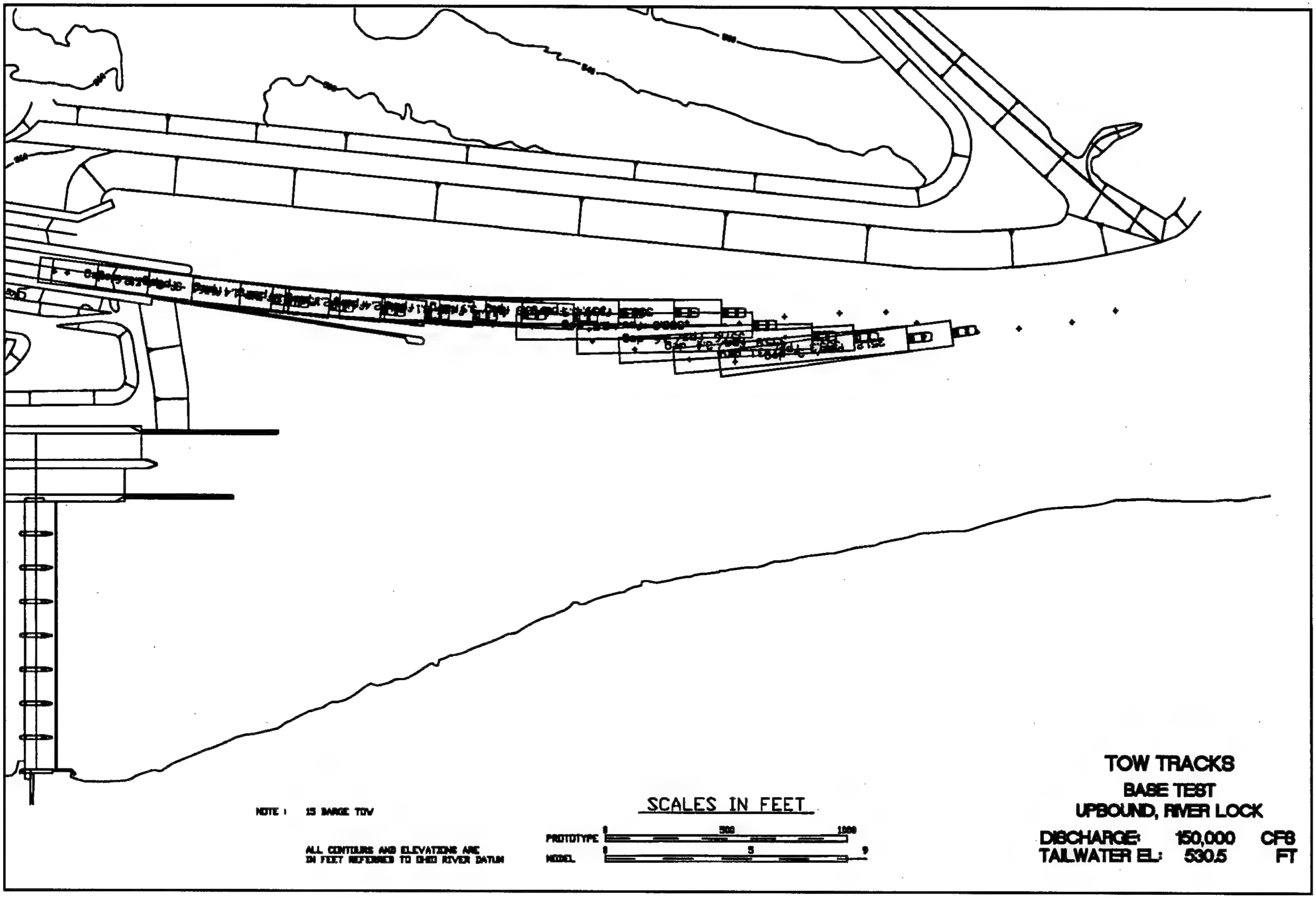

MOTD 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE
0
500
1000
MODEL
0
5
9
TOW TRACKS
BASE TEST
UPBOUND, LAND LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT

Plate 6


TOW TRACKS
BASE TEST
UPBOUND, RIVER LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM

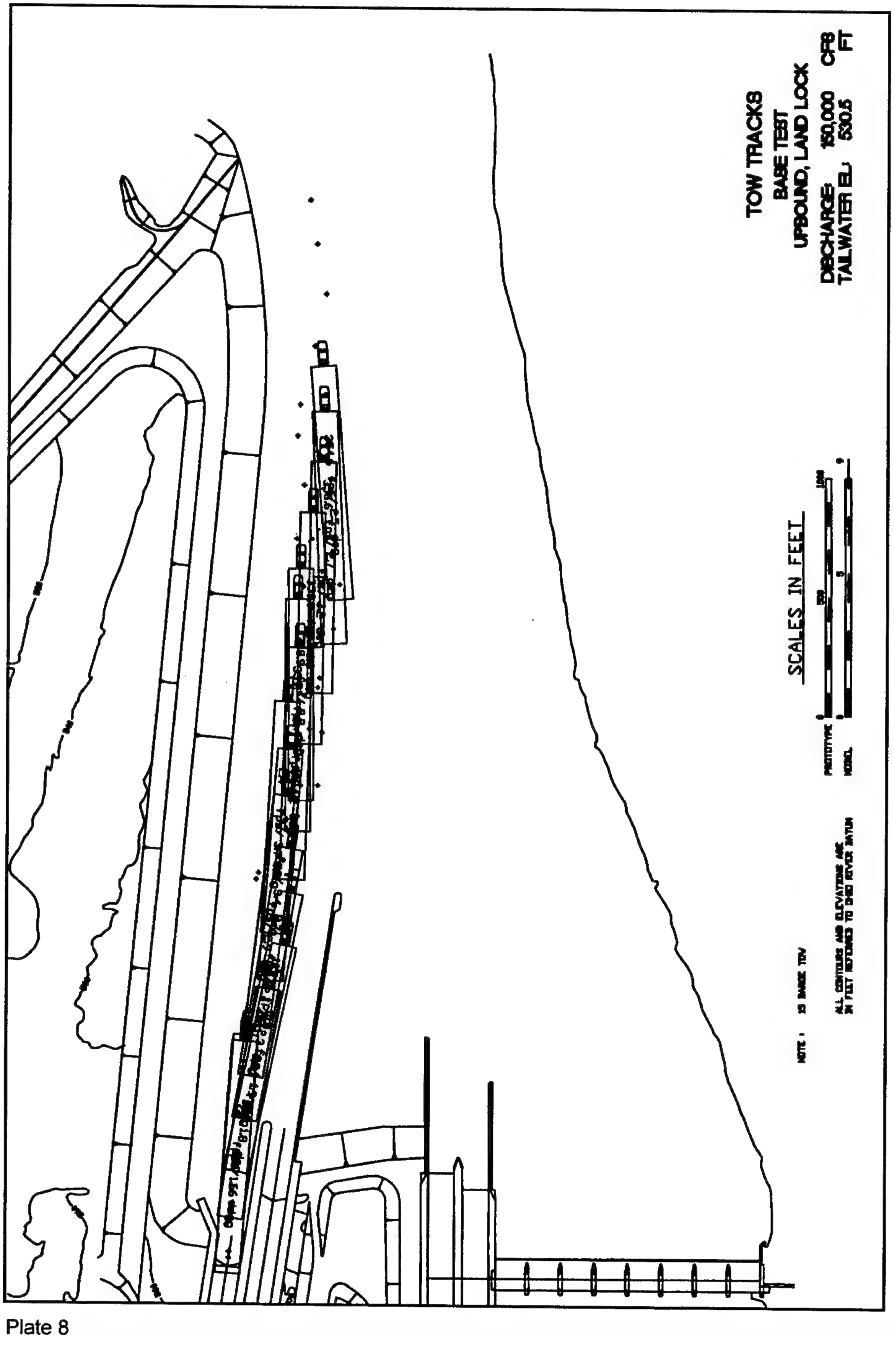
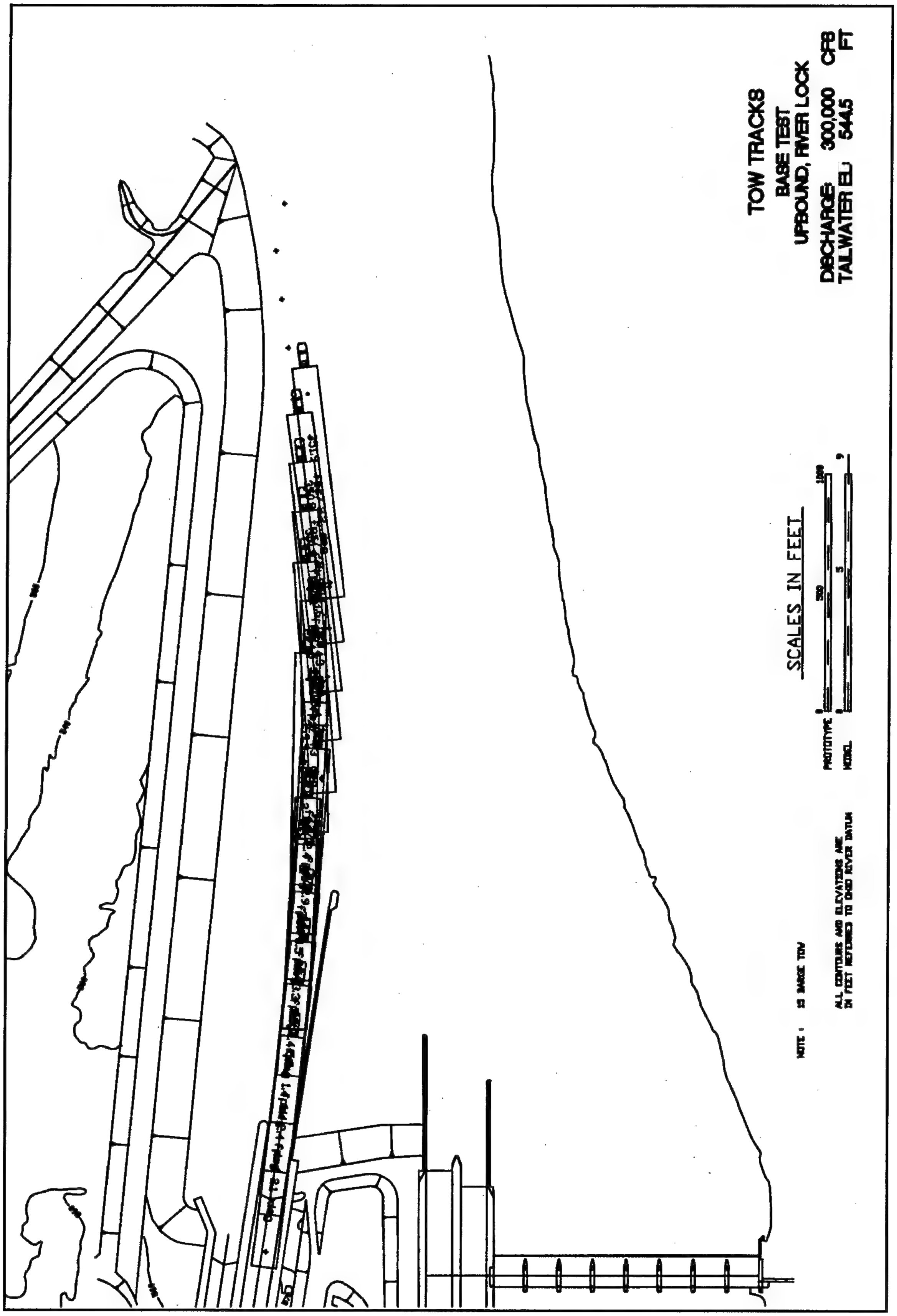

TOW TRACKS
BASE TEST
UPBOUND, LAND LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 8



TOW TRACKS
BASE TEST
UPBOUND, RIVER LOCK
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

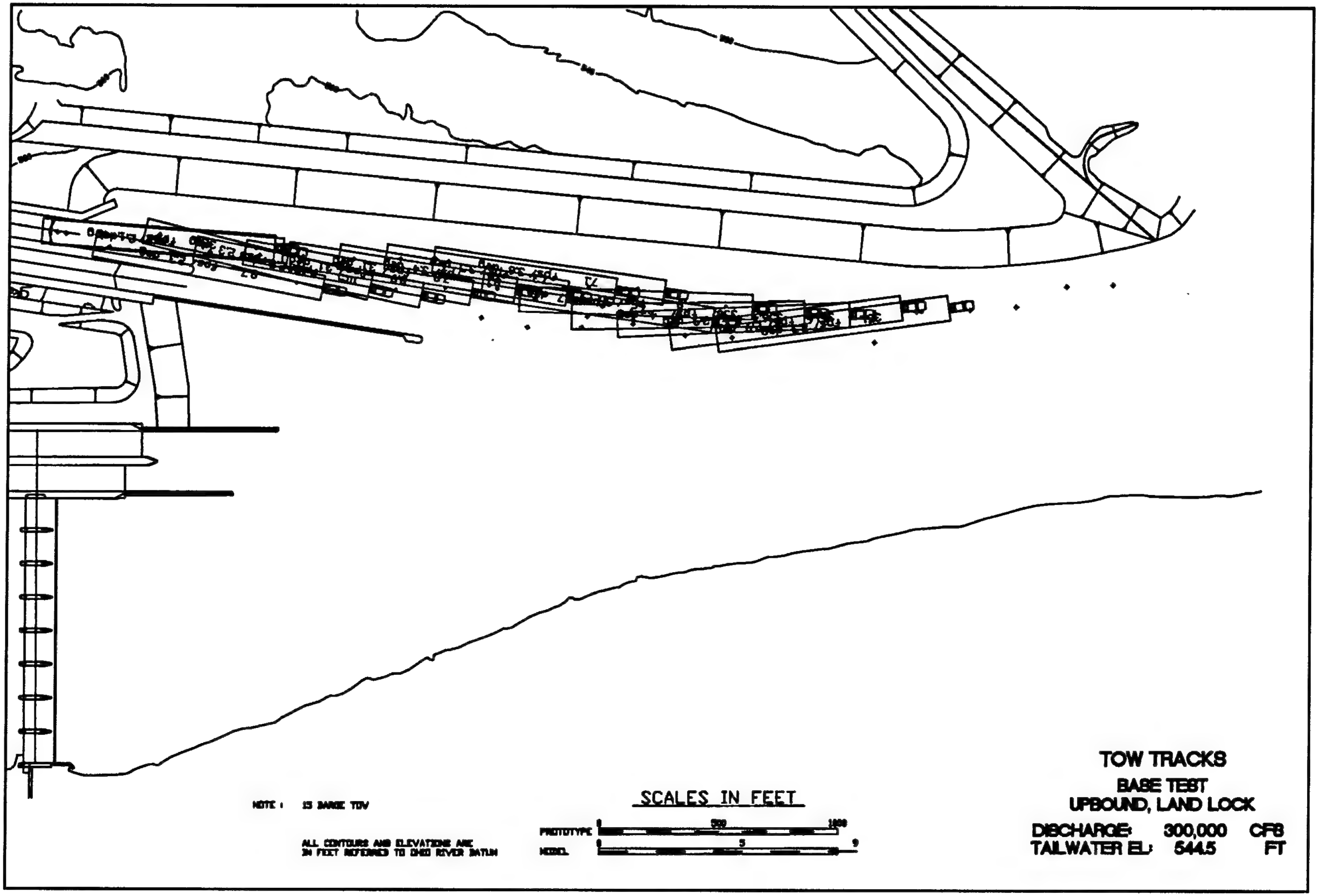
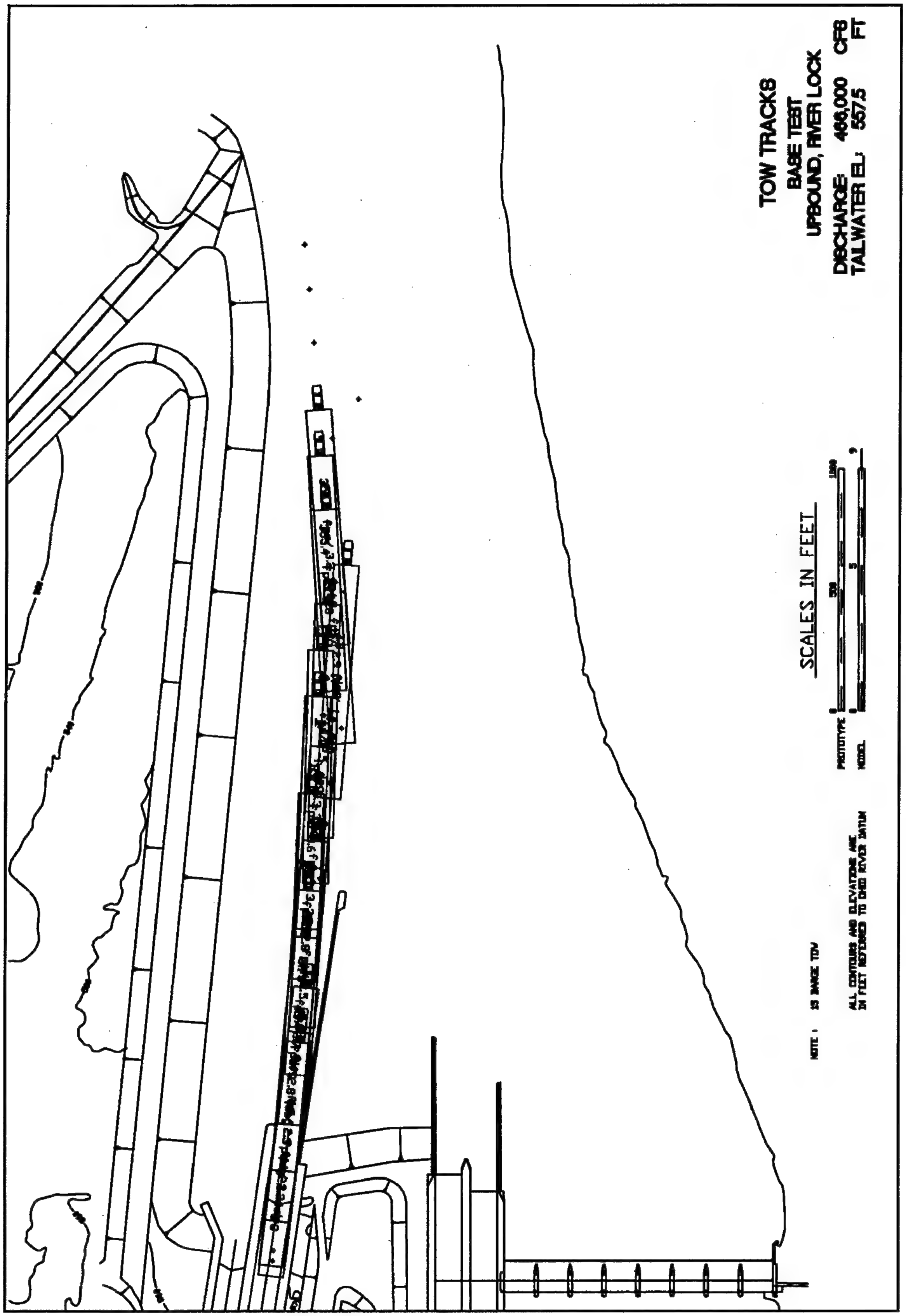
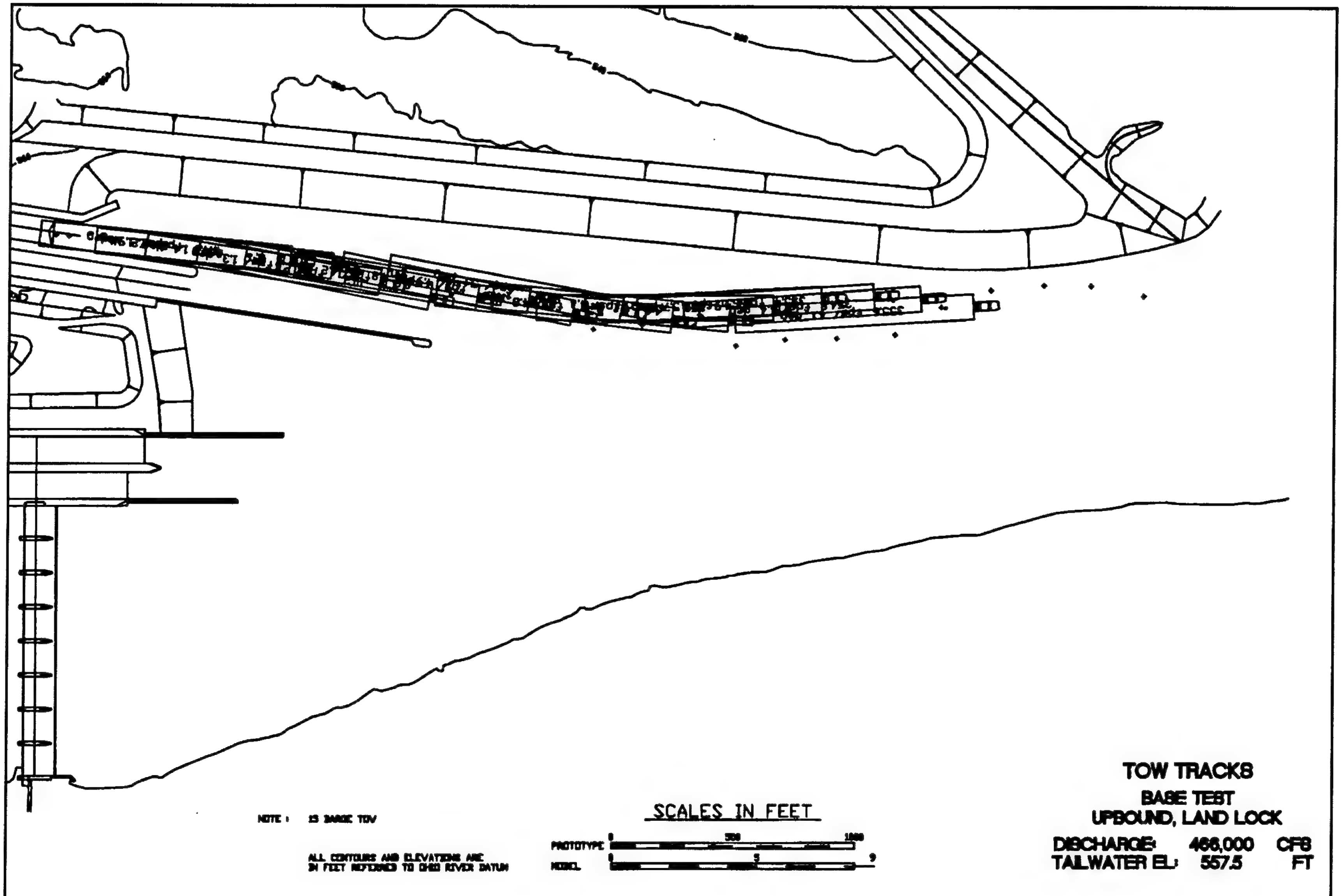

TOW TRACKS
BASE TEST
UPBOUND, LAND LOCK
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM

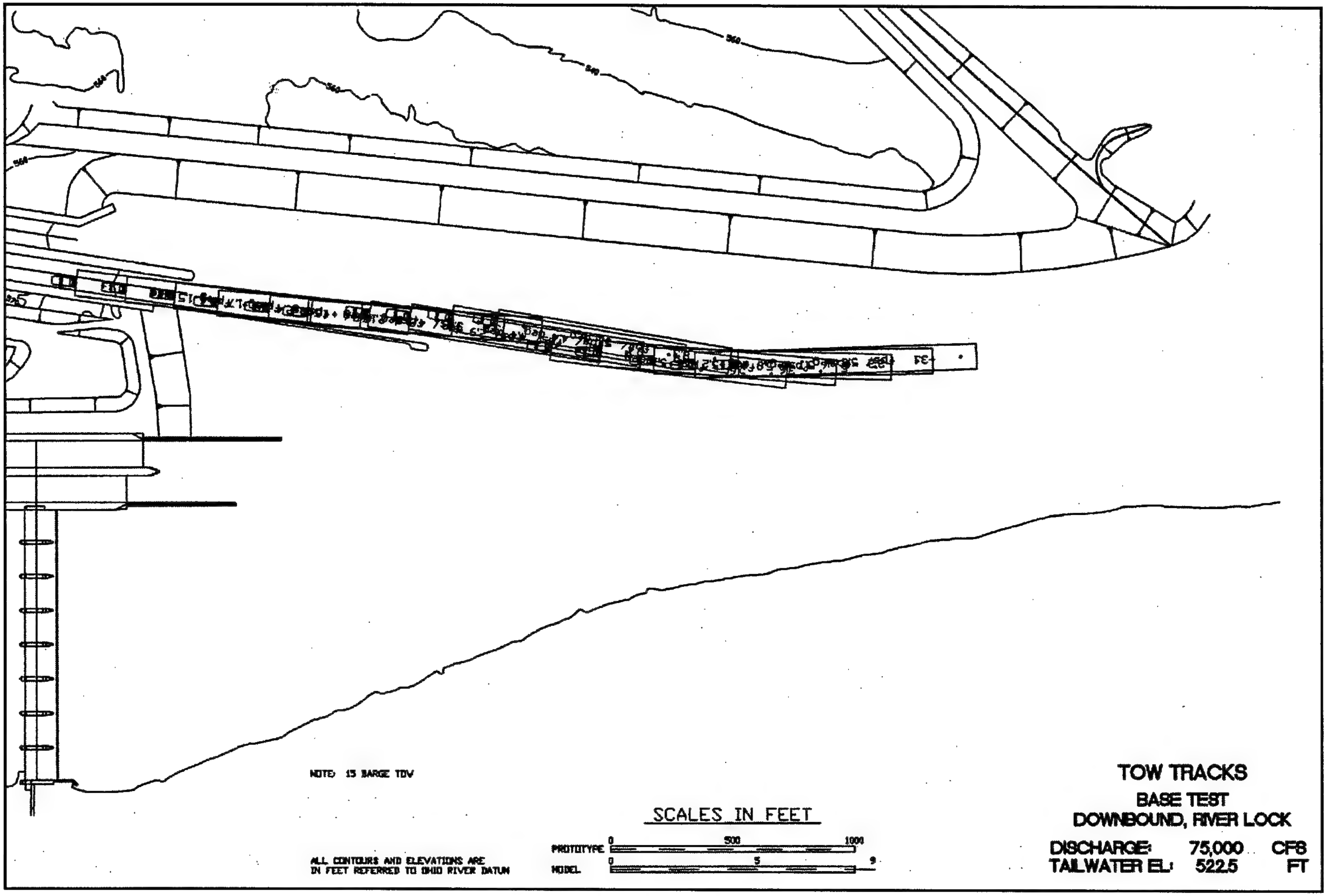
Plate 10


TOW TRACKS
BASE TEST
UPBOUND, RIVER LOCK
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 10
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM



TOW TRACKS
BASE TEST
UPBOUND, LAND LOCK
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 12



NOTE: 15 BARGE TOW
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
TOW TRACKS
BASE TEST
DOWNBOUND, RIVER LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT

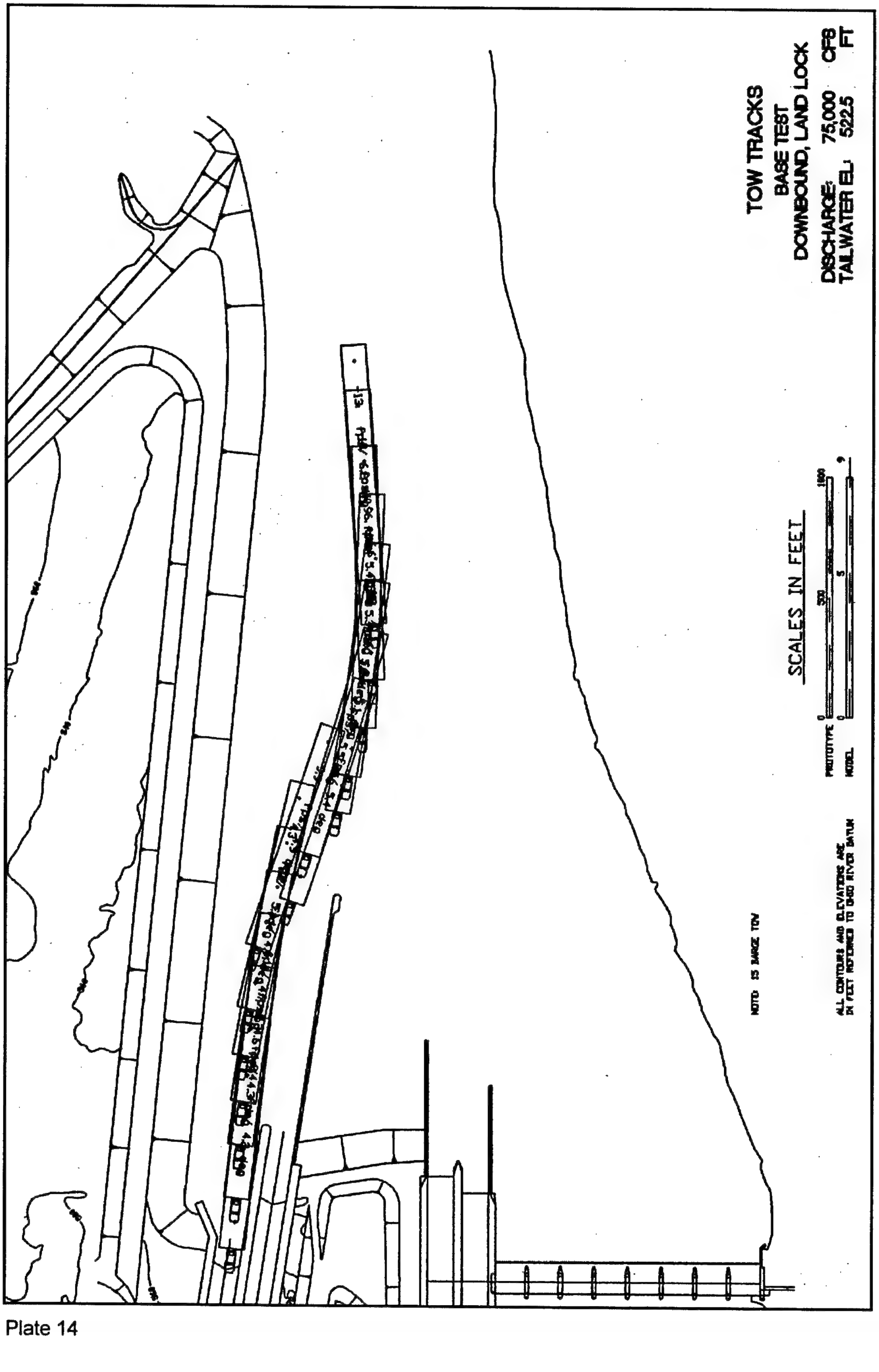
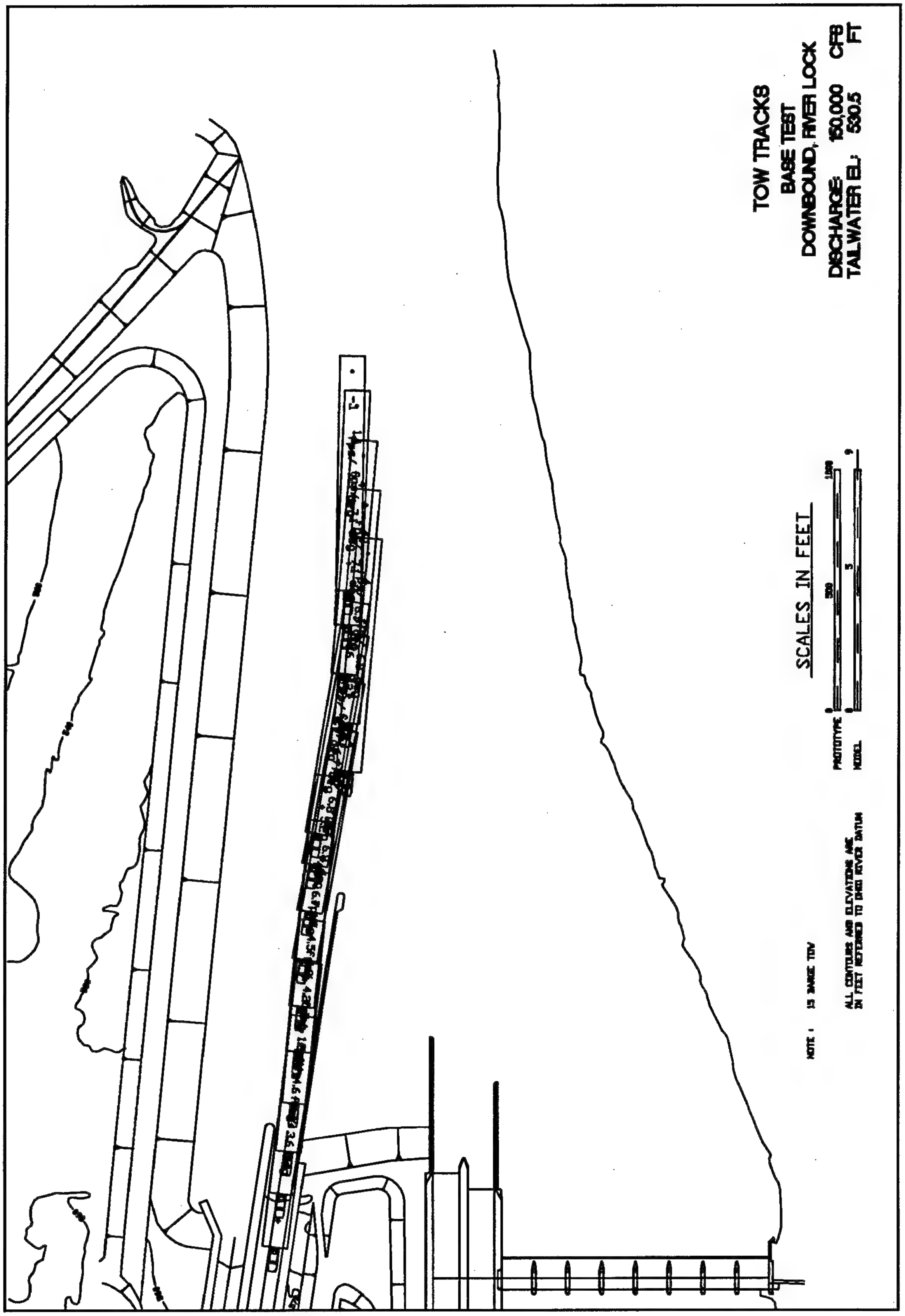

TOW TRACKS
BASE TEST
DOWNBOUND, LAND LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 14



TOW TRACKS
BASE TEST
DOWNBOUND, RIVER LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

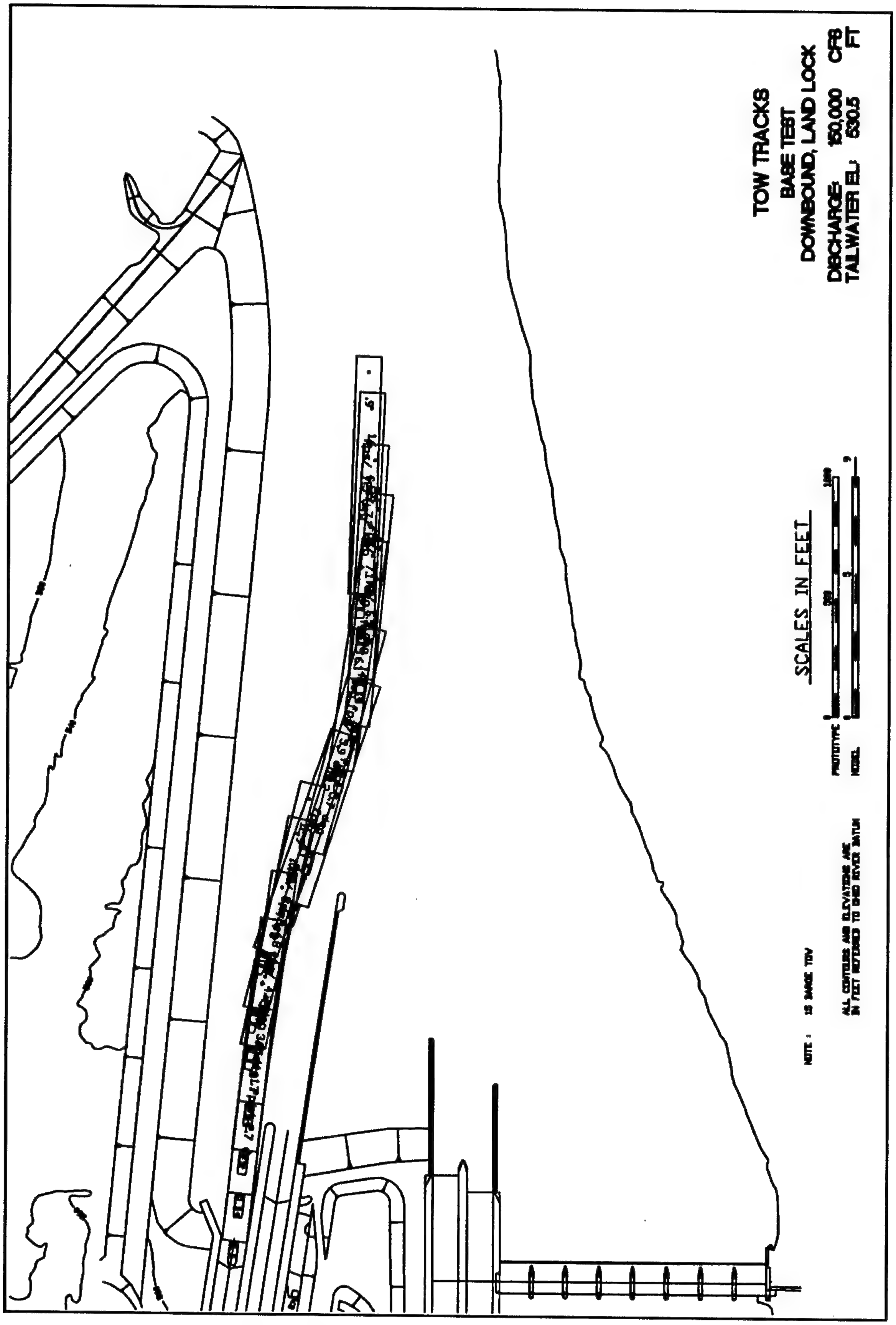

TOW TRACKS
BASE TEST
DOWNBOUND, LAND LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 16

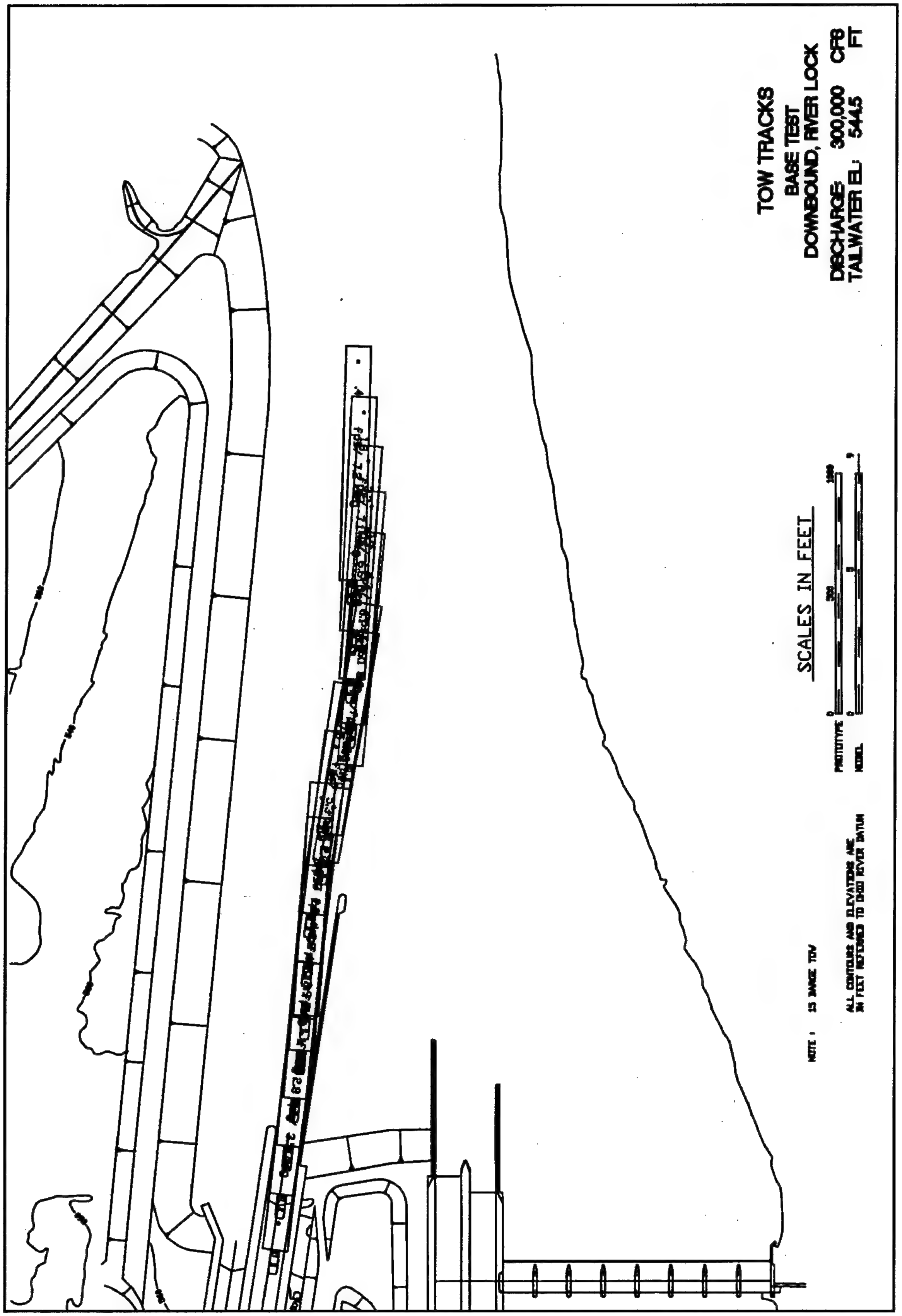
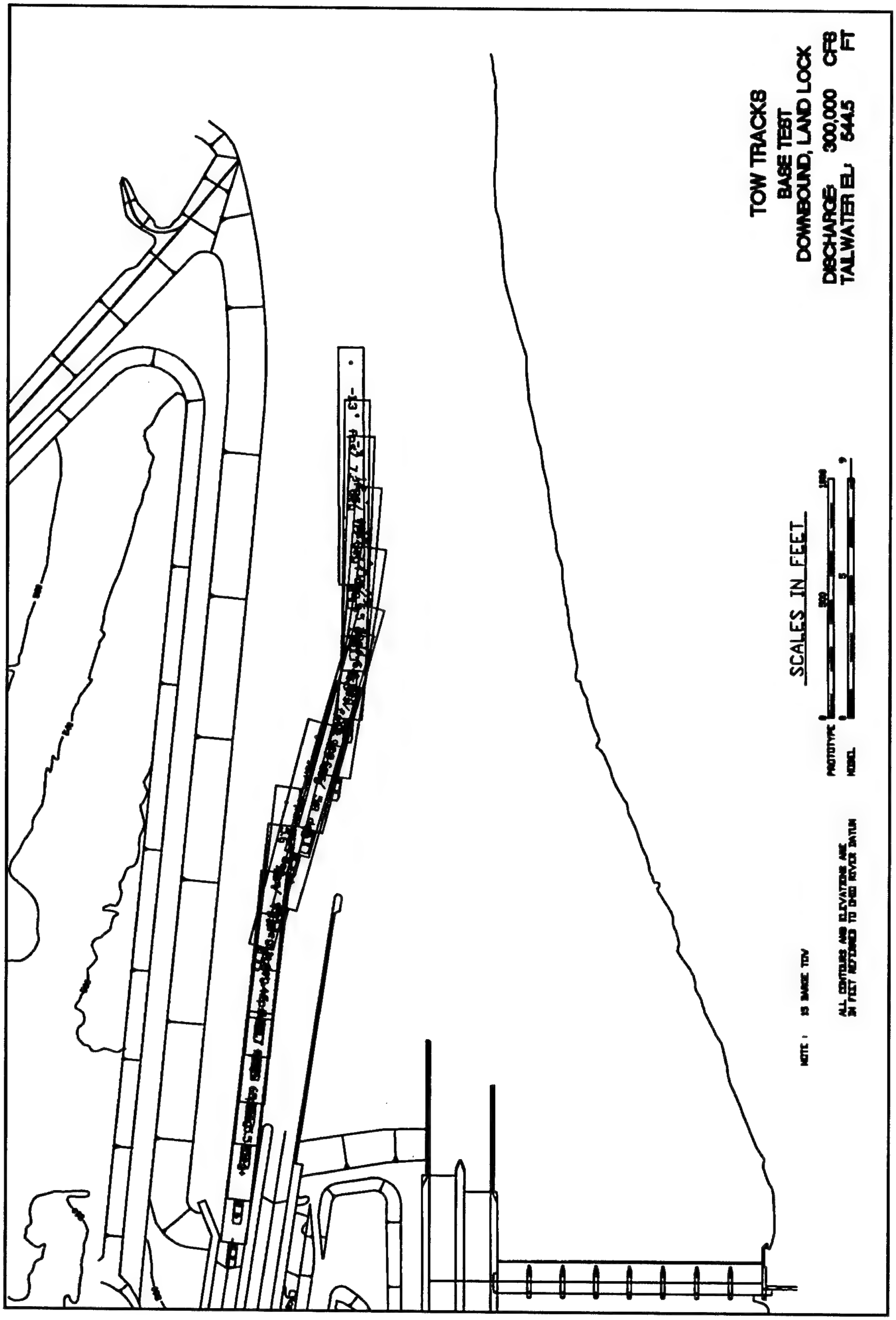
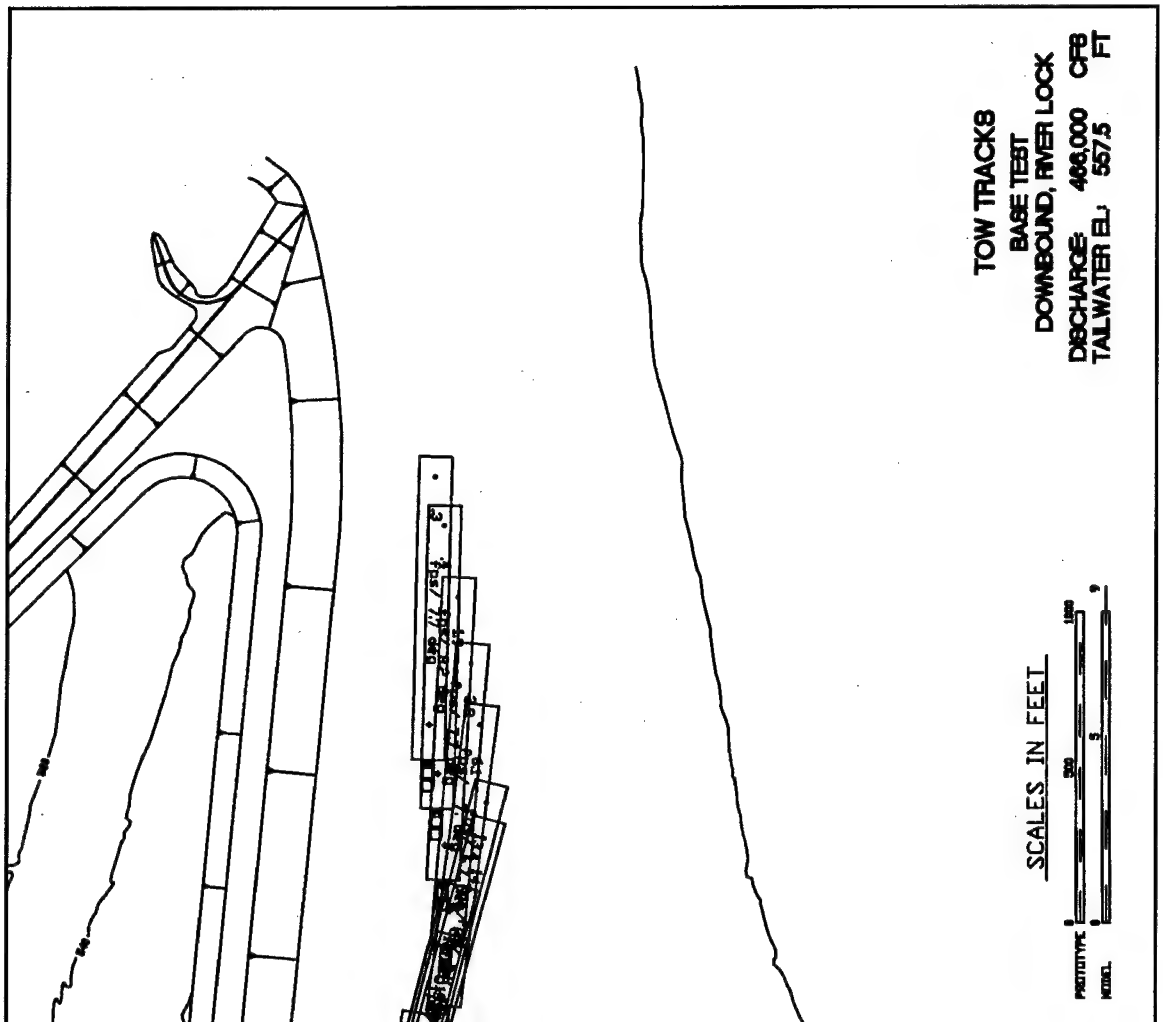

TOW TRACKS
BASE TEST
DOWNBOUND, RIVER LOCK
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 17



TOW TRACKS
BASE TEST
DOWNBOUND, LAND LOCK
DISCHARGE, 300,000 CFS
TAILWATER EL, 544.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 18


TOW TRACKS
BASE TEST
DOWNBOUND, RIVER LOCK
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

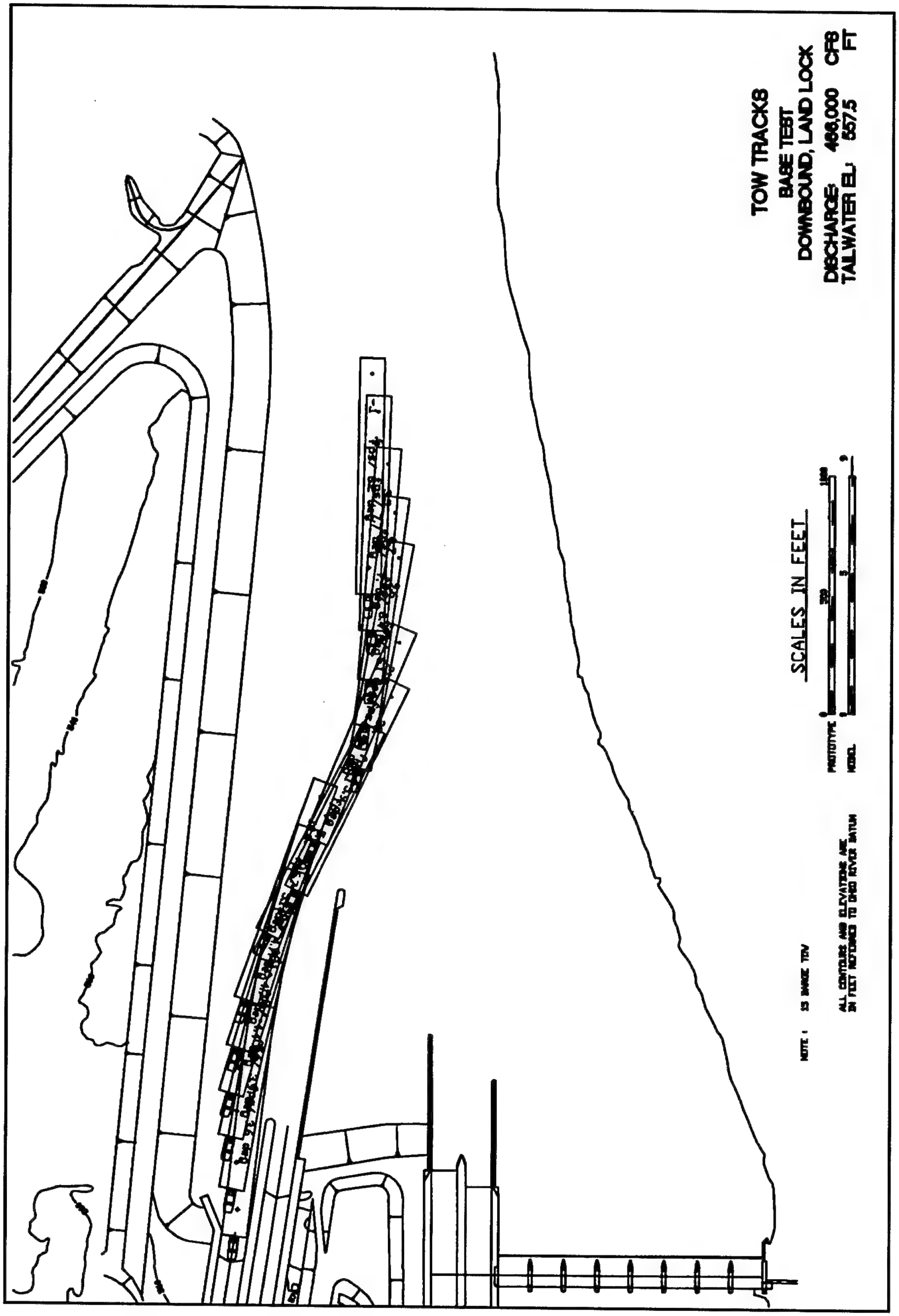
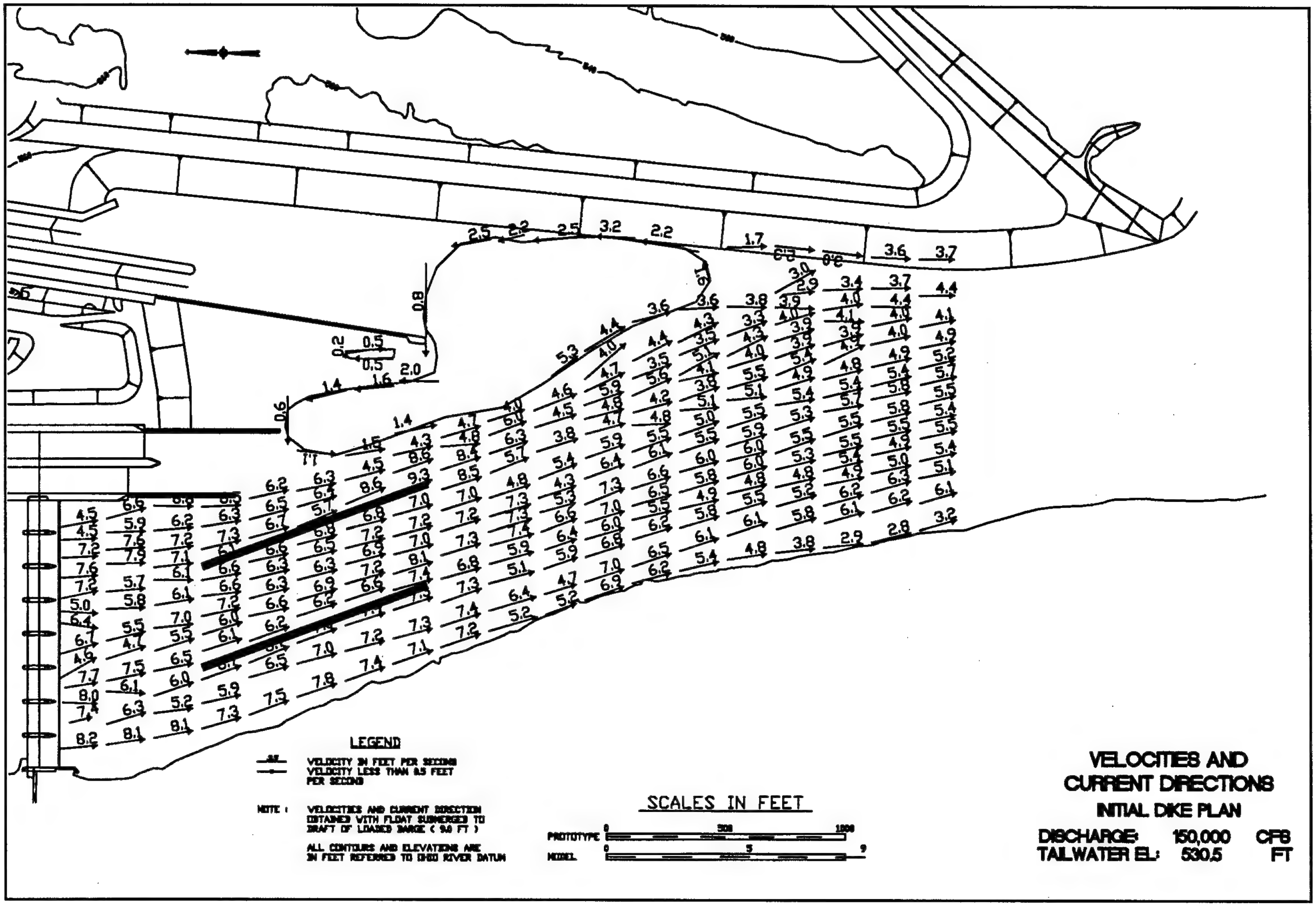

TOW TRACKS
BASE TEST
DOWNBOUND, LAND LOCK
DISCHARGE 466,000 CFS
TAILWATER EL. 557.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERENCE TO OHIO RIVER DATUM

Plate 20


VELOCITIES AND
CURRENT DIRECTIONS
INITIAL DIKE PLAN
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE
MODEL

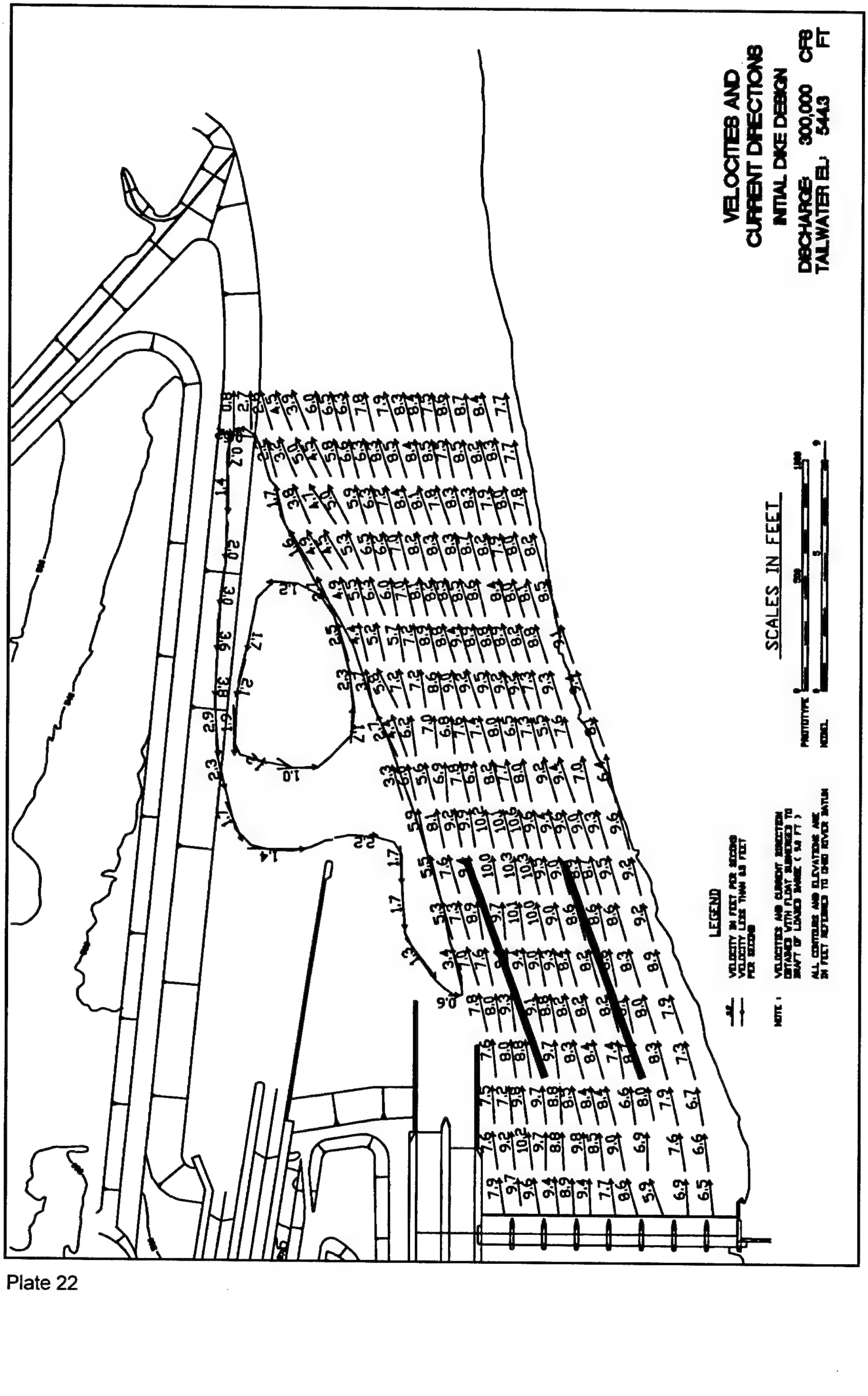
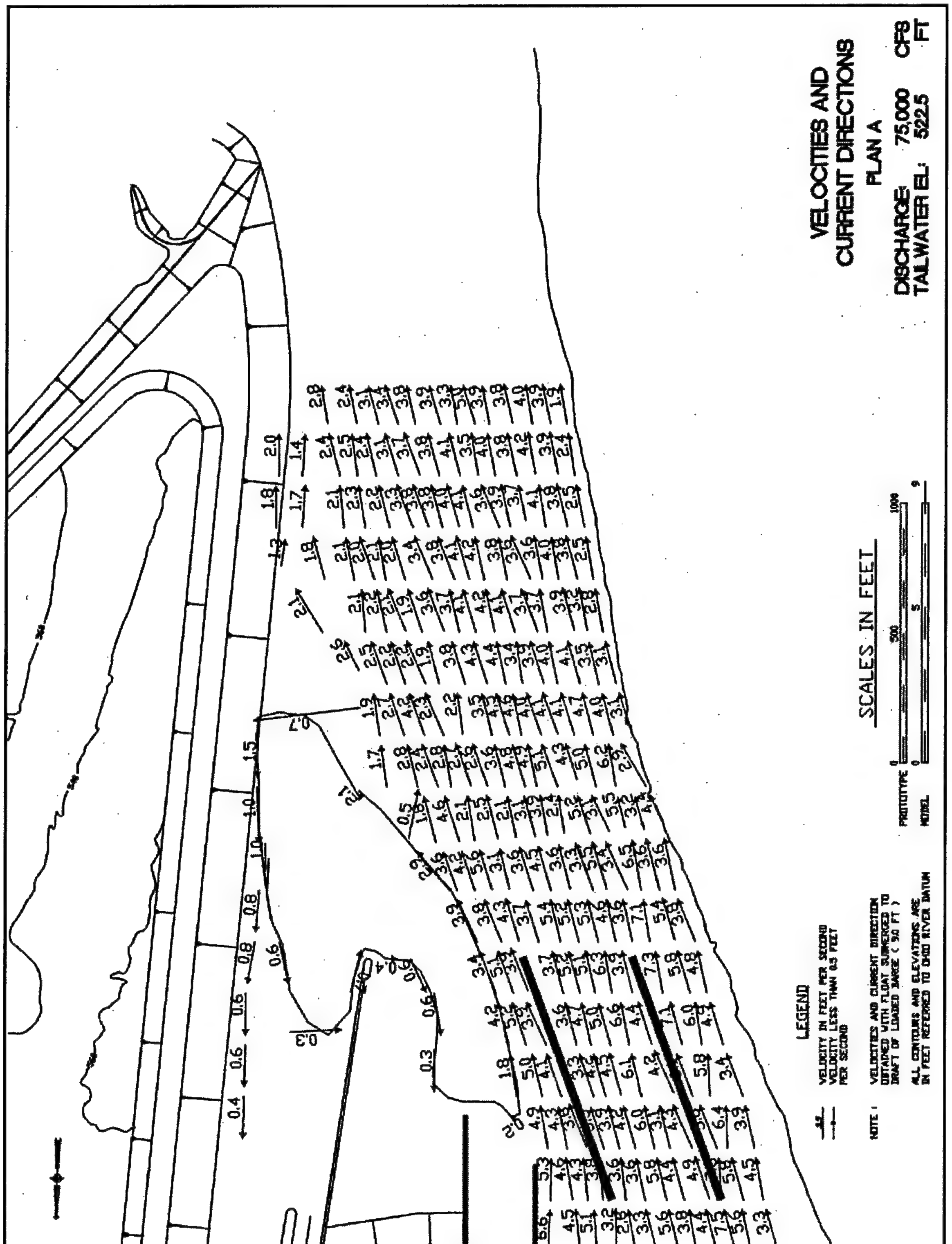

VELOCITIES AND CURRENT DIRECTIONS
INITIAL DIKE DESIGN
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.3 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND

Plate 22


VELOCITIES AND
CURRENT DIRECTIONS
PLAN A
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

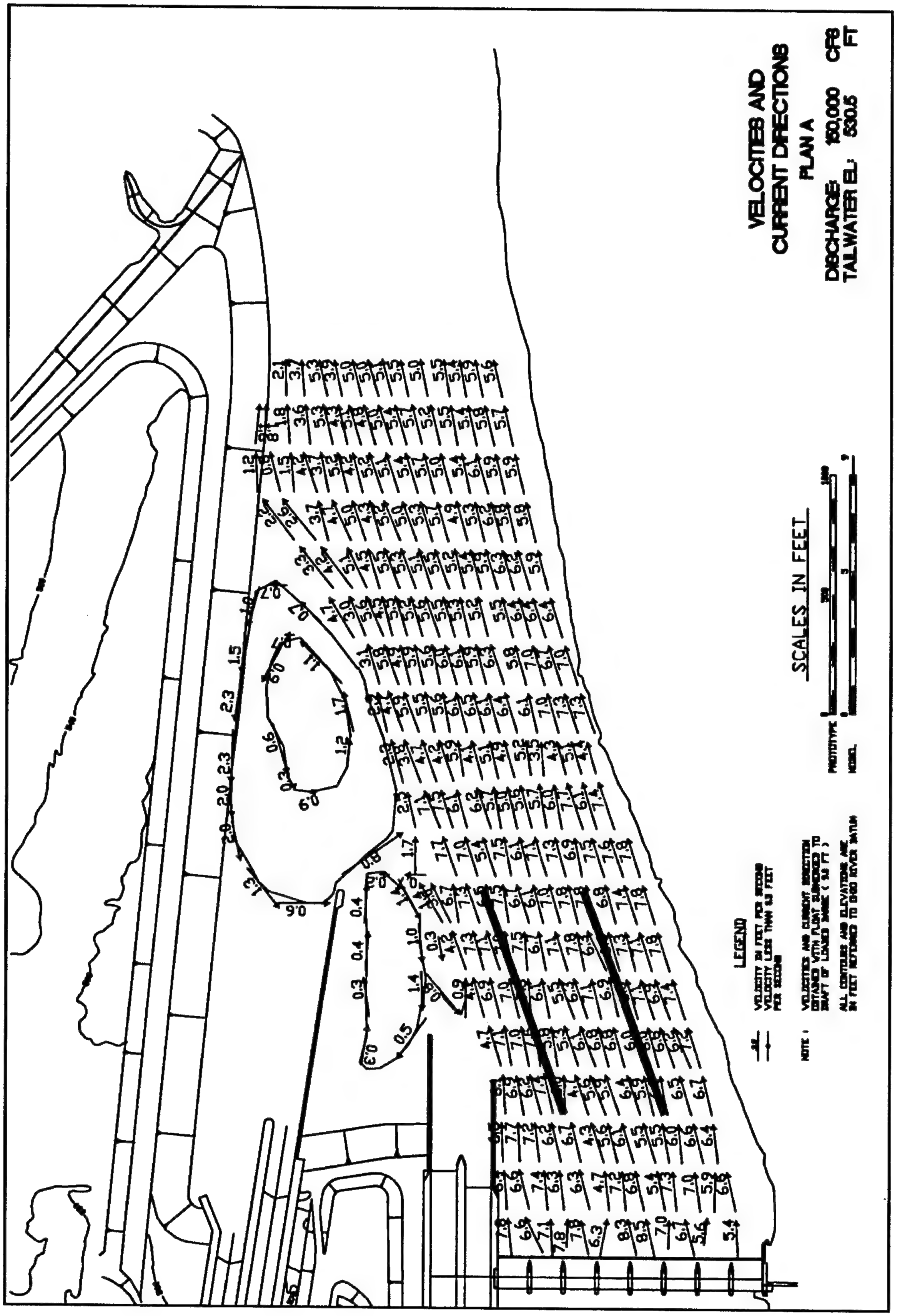

VELOCITIES AND CURRENT DIRECTIONS
PLAN A
DISCHARGE: 150,000 CFS
TAILWATER EL. 530.5 FT
SCALES IN FEET
LEGEND

Plate 24

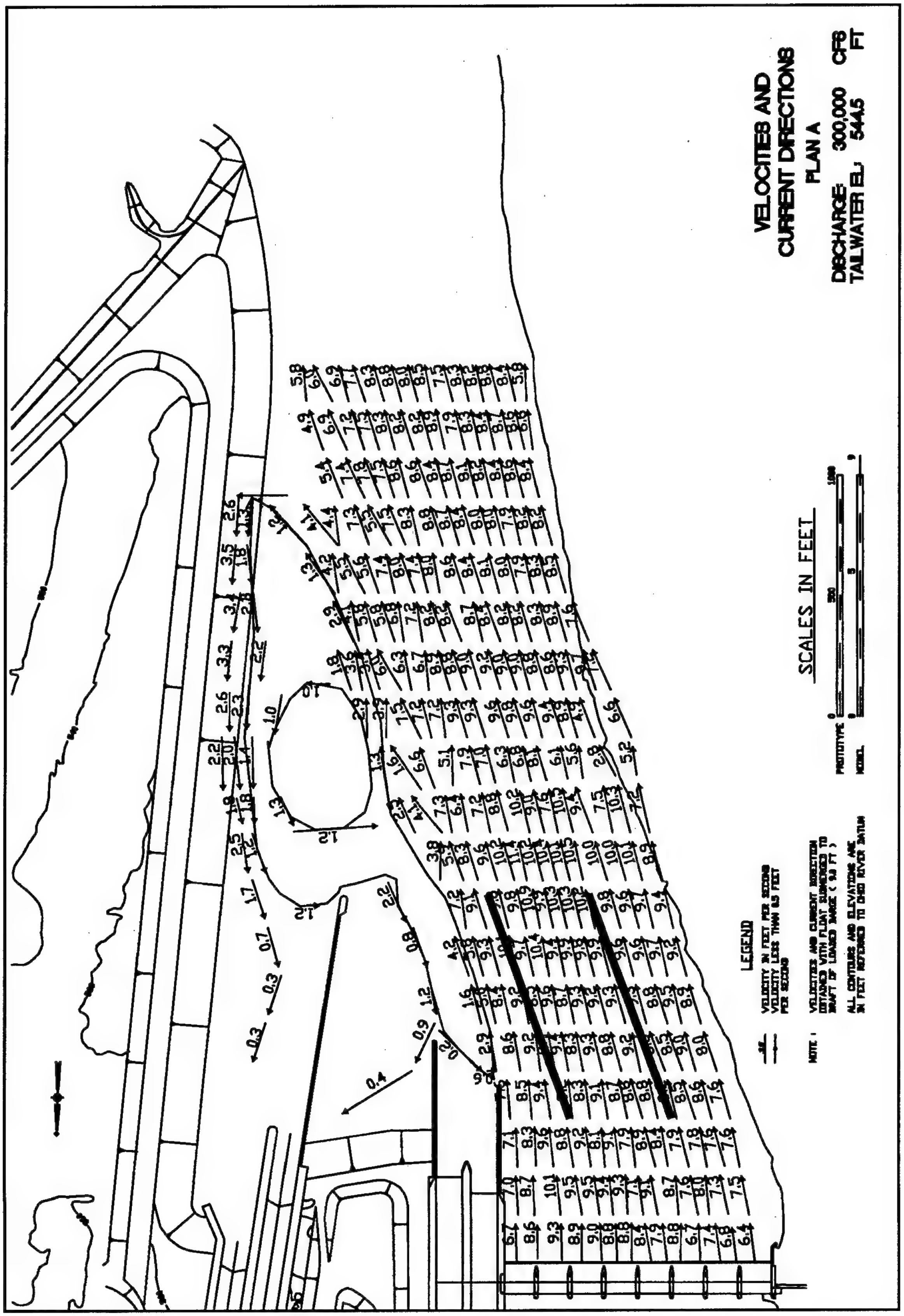
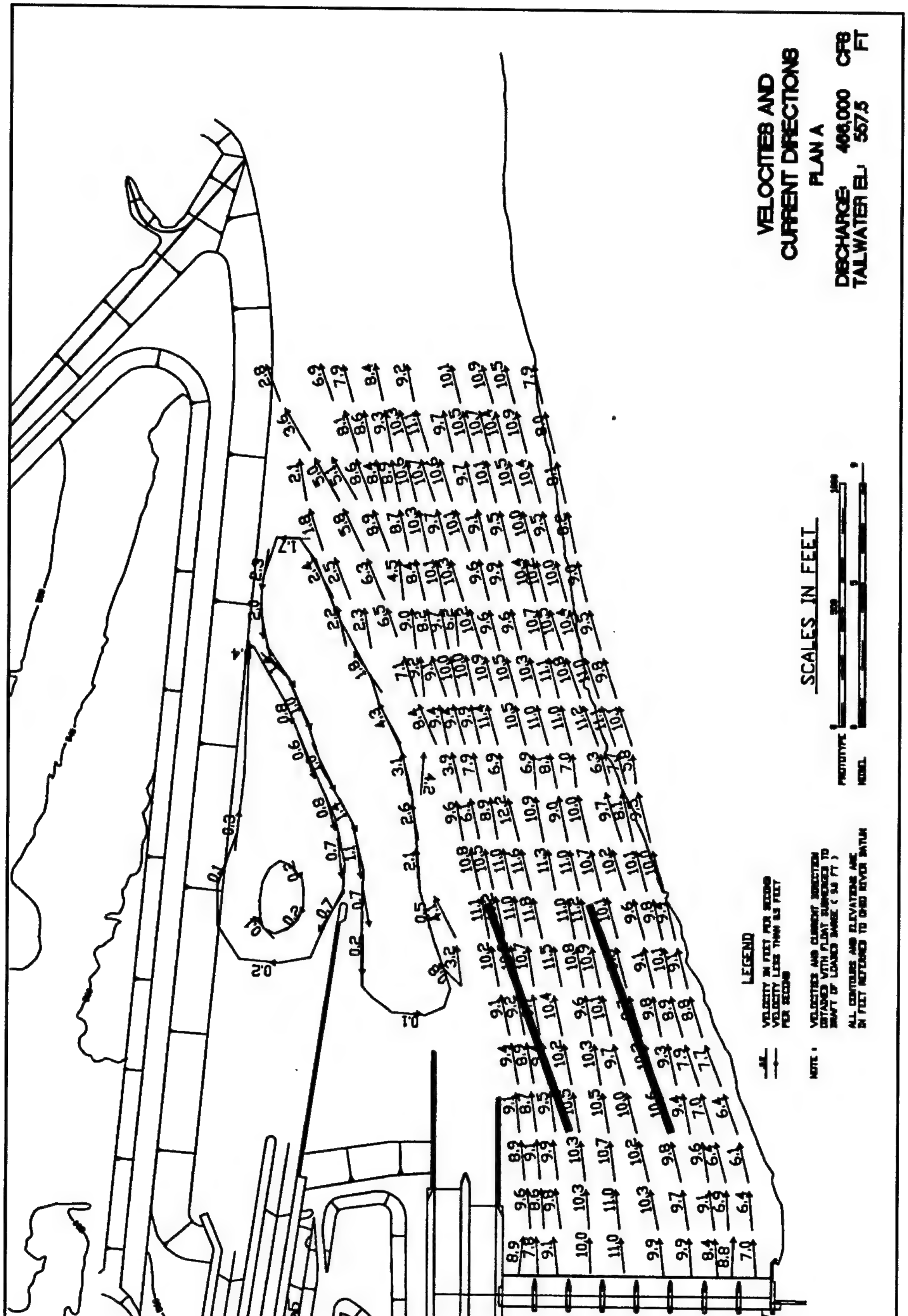
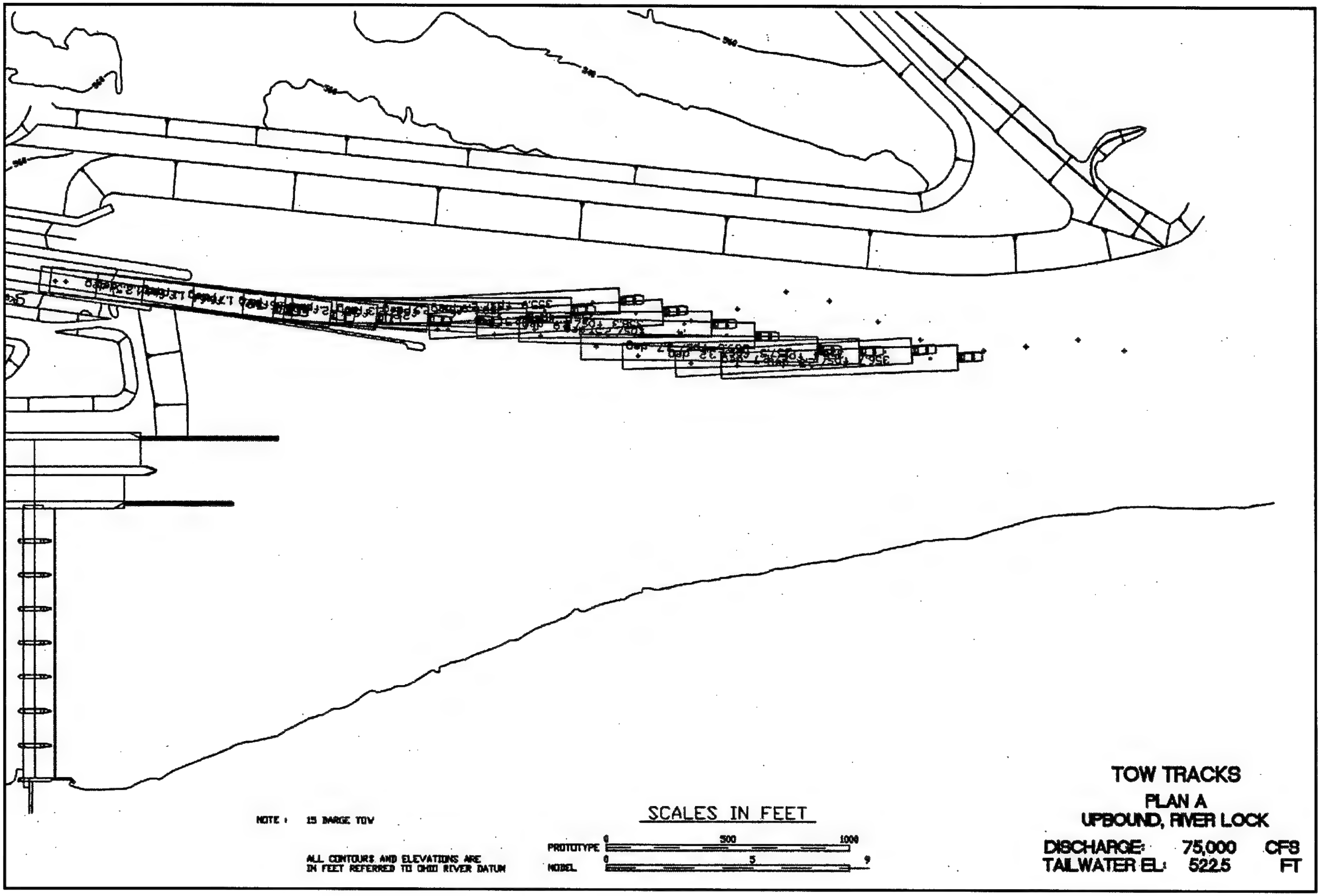

VELOCITIES AND
CURRENT DIRECTIONS
PLAN A
DISCHARGE: 300,000 CFS
TAILWATER EL. 544.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 25


VELOCITIES AND
CURRENT DIRECTIONS
PLAN A
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM


TOW TRACKS
PLAN A
UPBOUND, RIVER LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

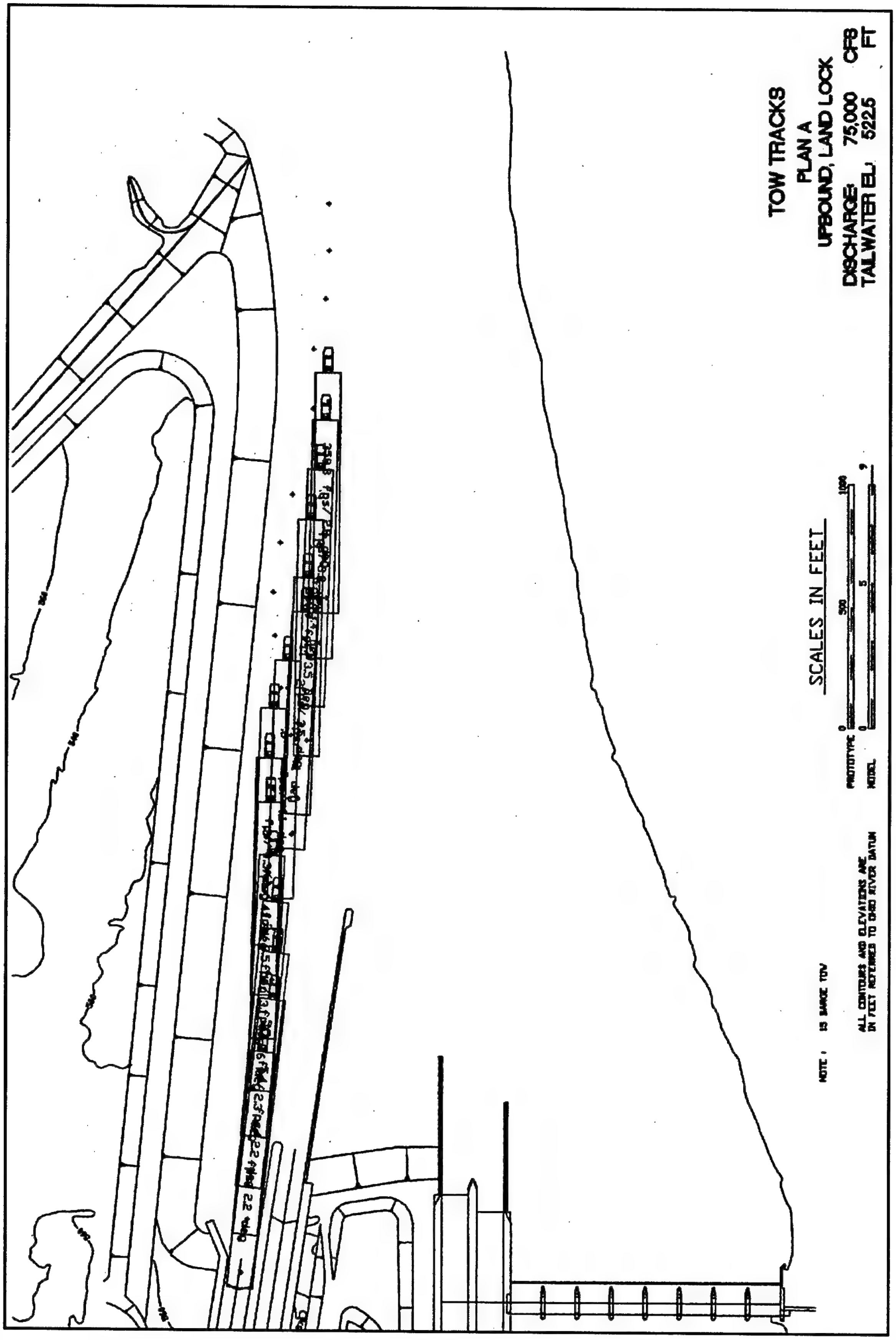

TOW TRACKS
PLAN A
UPBOUND, LAND LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL 522.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 28

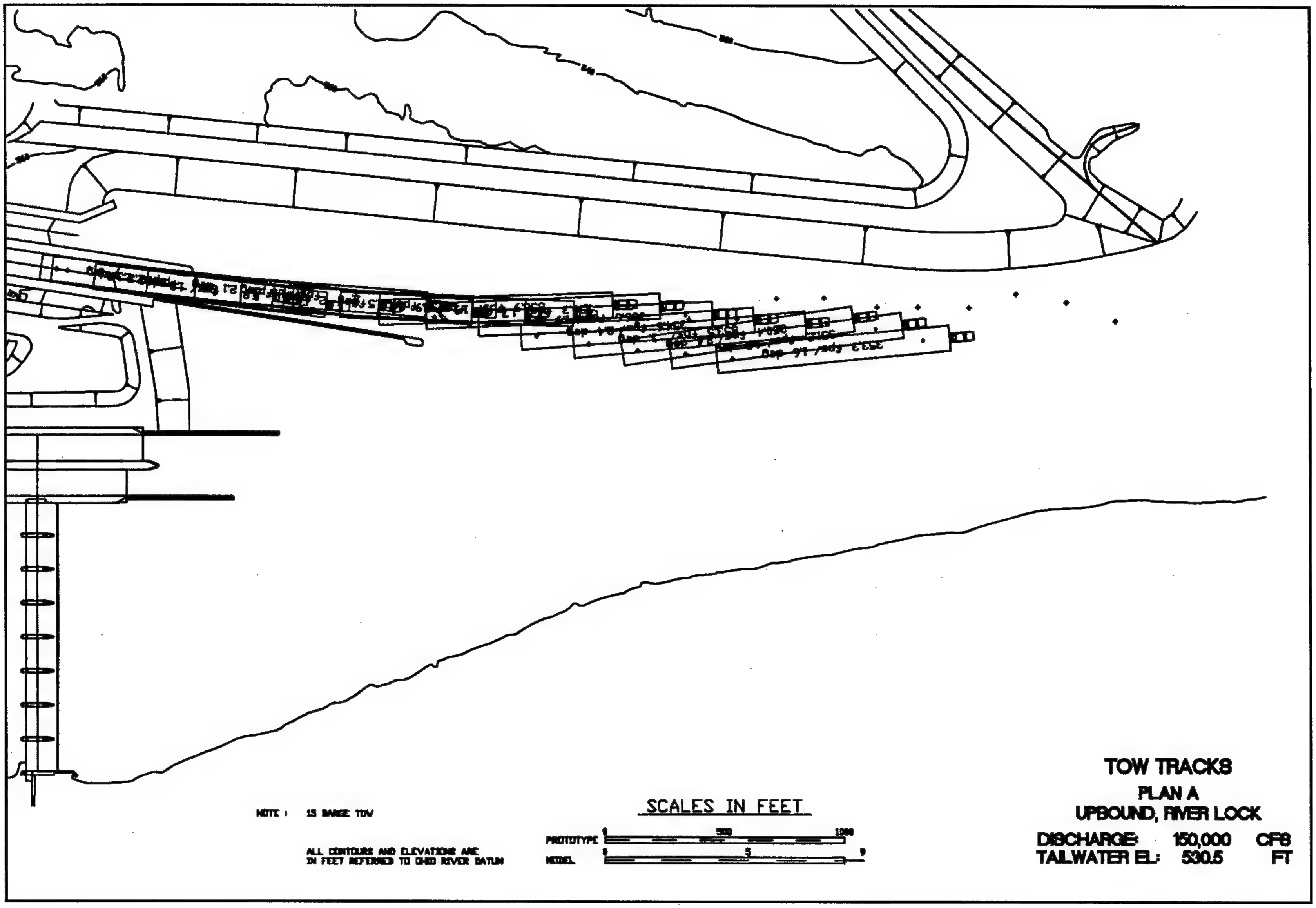

TOW TRACKS
PLAN A
UPBOUND, RIVER LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET
PROTOTYPE
0
500
1000
MODEL
0
5
9
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM

Plate 29

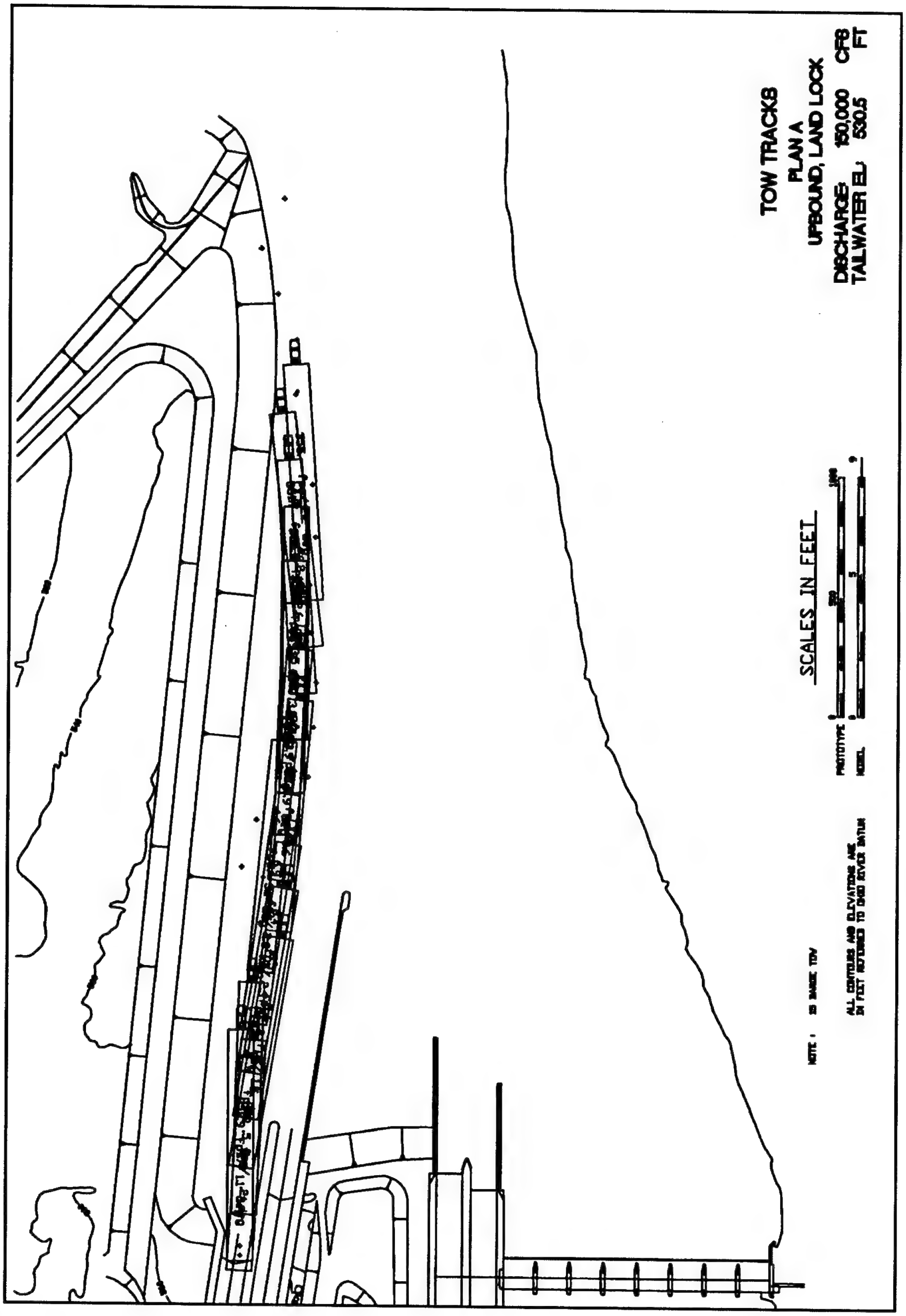
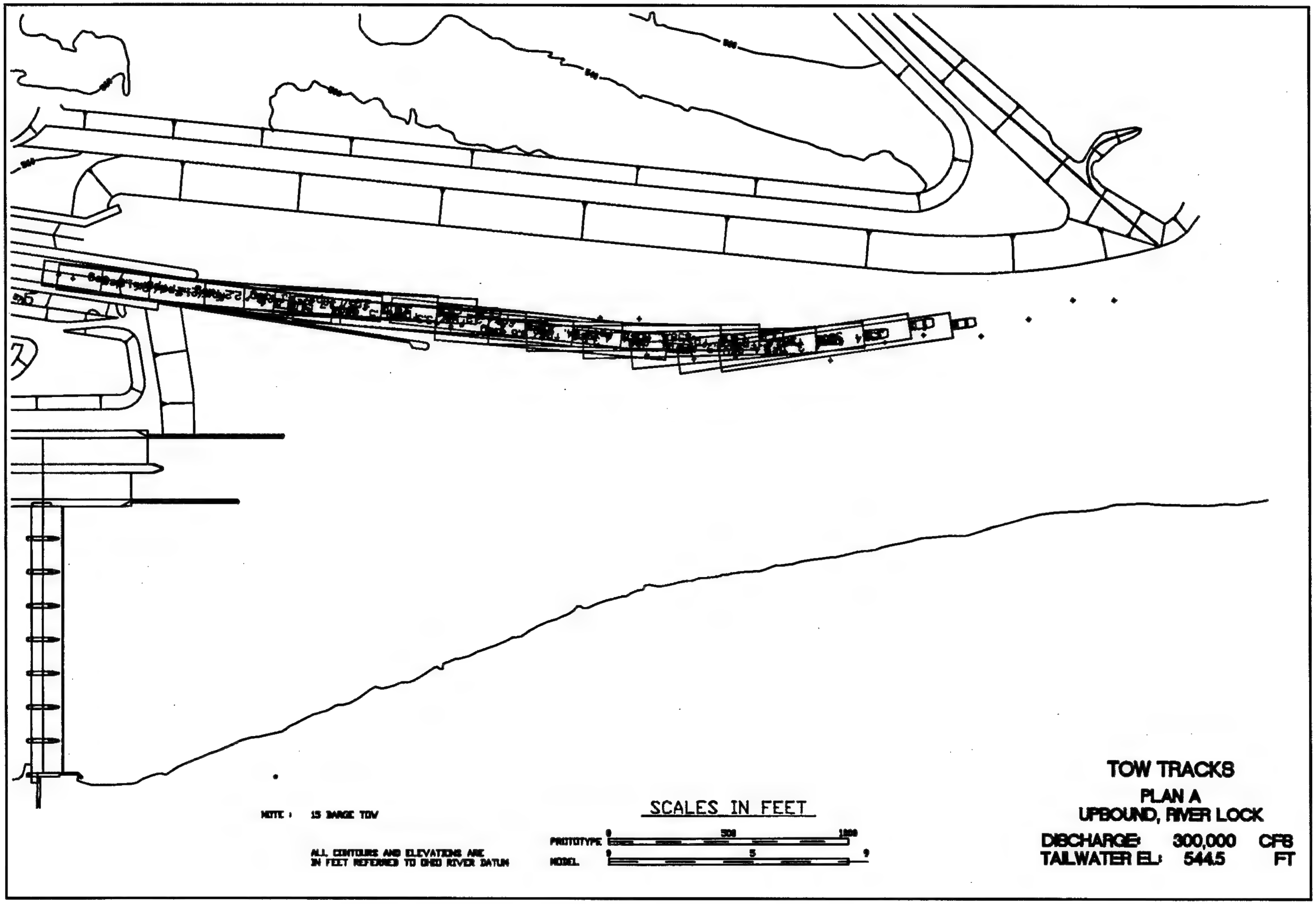

TOW TRACKS
PLAN A
UPBOUND, LAND LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET

Plate 30


TOW TRACKS
PLAN A
UPBOUND, RIVER LOCK
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

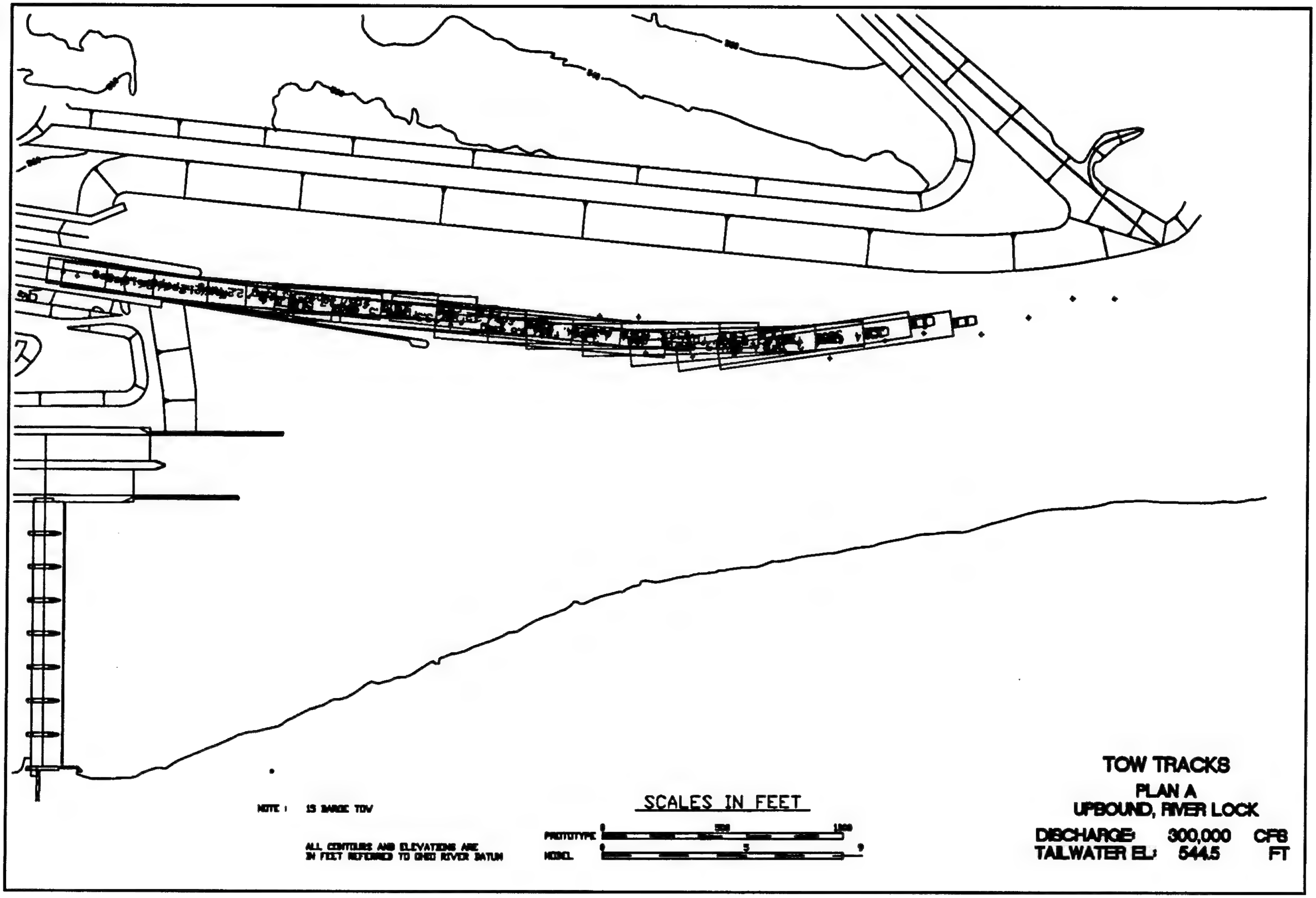
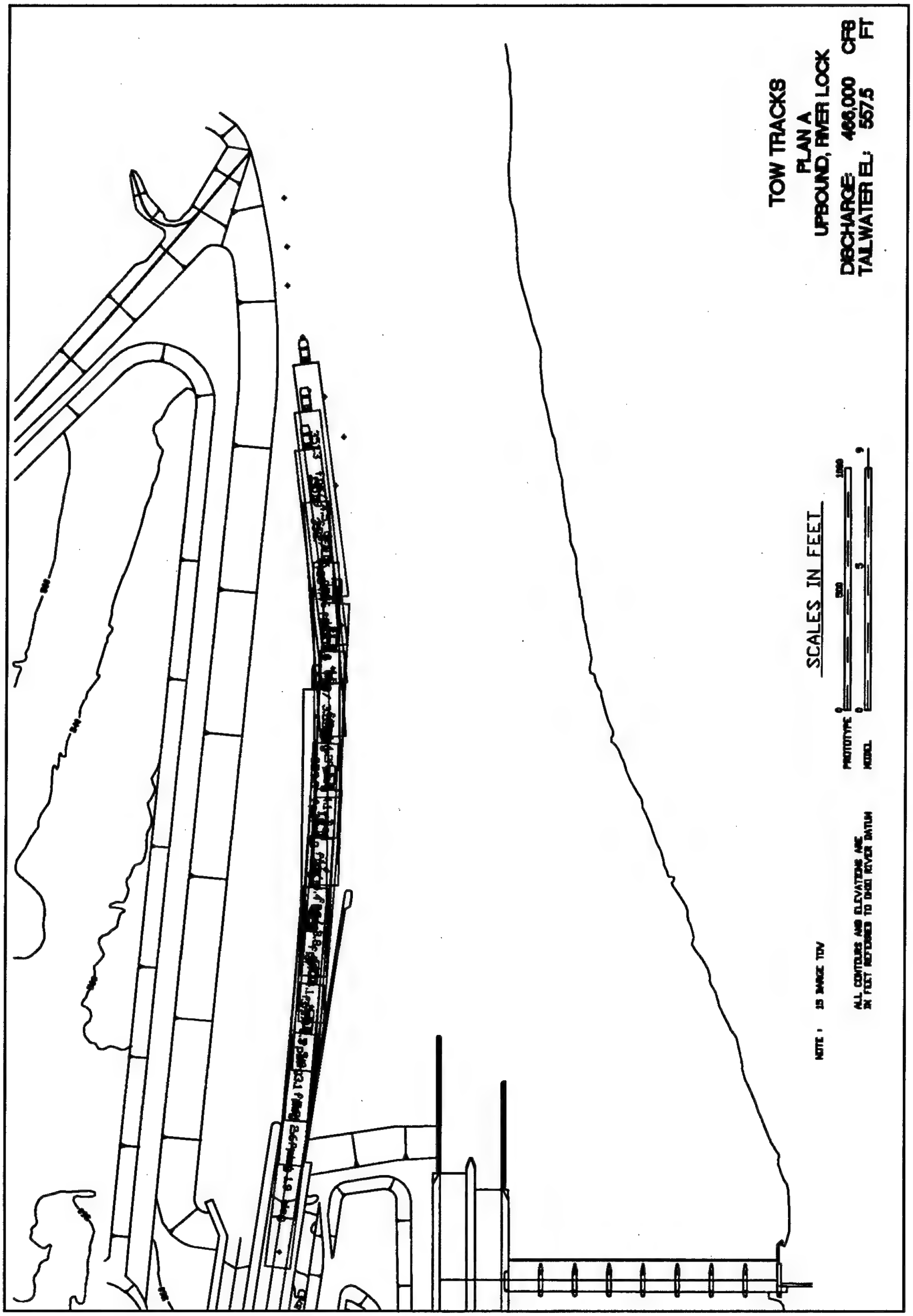

TOW TRACKS
PLAN A
UPBOUND, RIVER LOCK
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 32



TOW TRACKS
PLAN A
UPBOUND, RIVER LOCK
DISCHARGE: 486,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 33

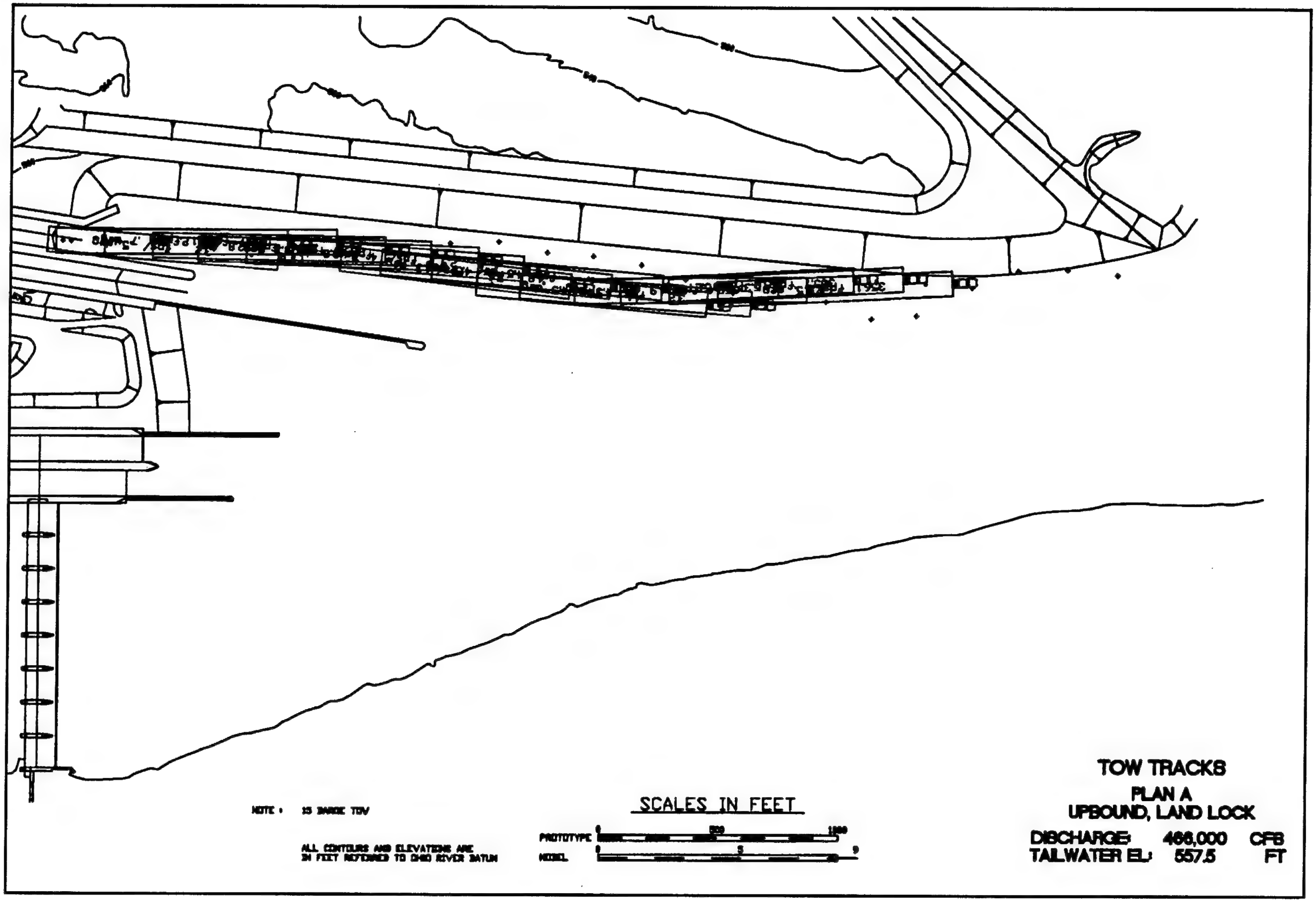
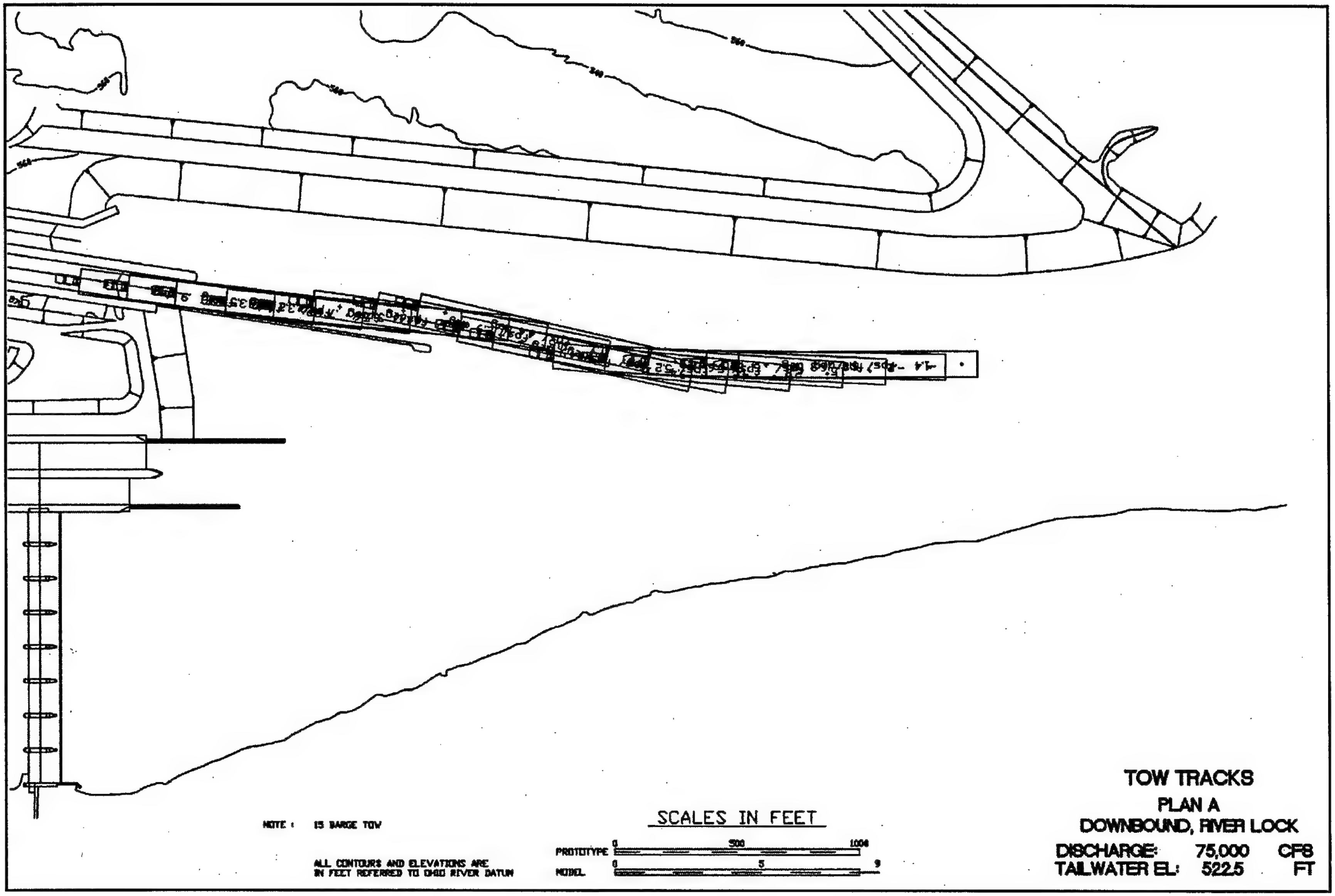

TOW TRACKS
PLAN A
UPBOUND, LAND LOCK
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM

Plate 34


TOW TRACKS
PLAN A
DOWNBOUND, RIVER LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

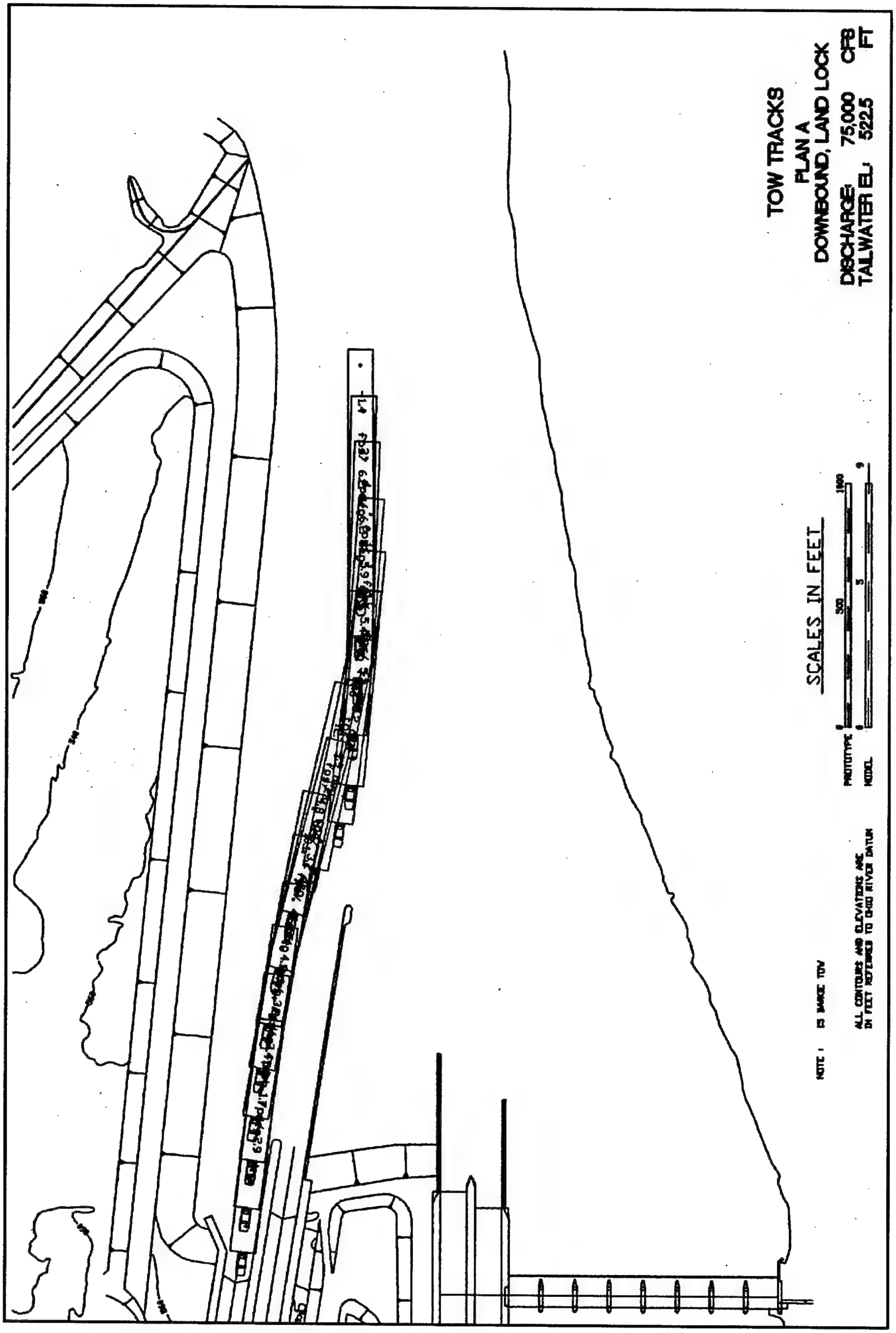
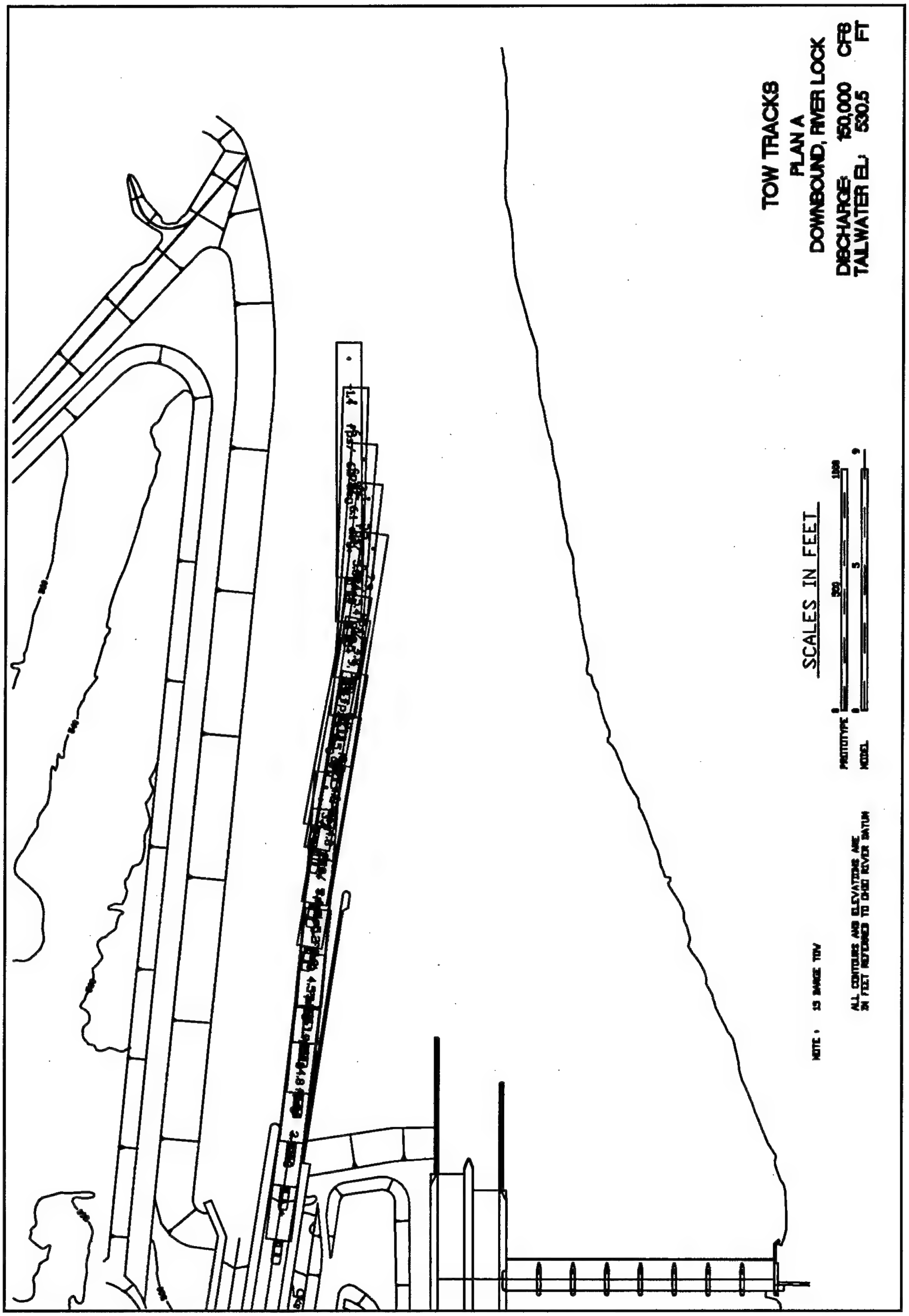

TOW TRACKS
PLAN A
DOWNBOUND, LAND LOCK
DISCHARGE: 75,000 CFS
TAILWATER EL. 522.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
0
500
1000
5
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM

Plate 36


TOW TRACKS
PLAN A
DOWNBOUND, RIVER LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5
NOTE: 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

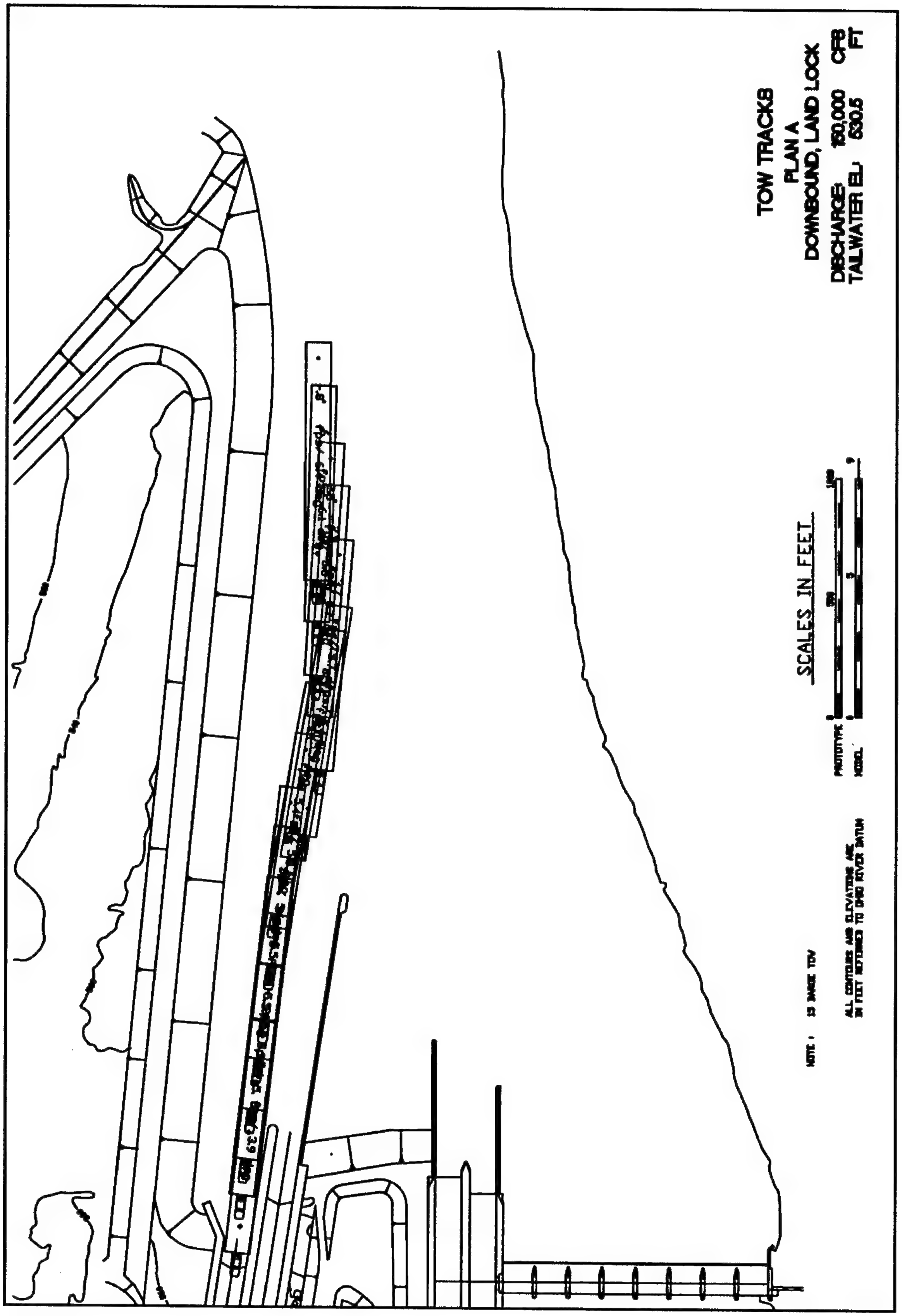

TOW TRACKS
PLAN A
DOWNBOUND, LAND LOCK
DISCHARGE: 150,000 CFS
TAILWATER EL. 530.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 10
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 38

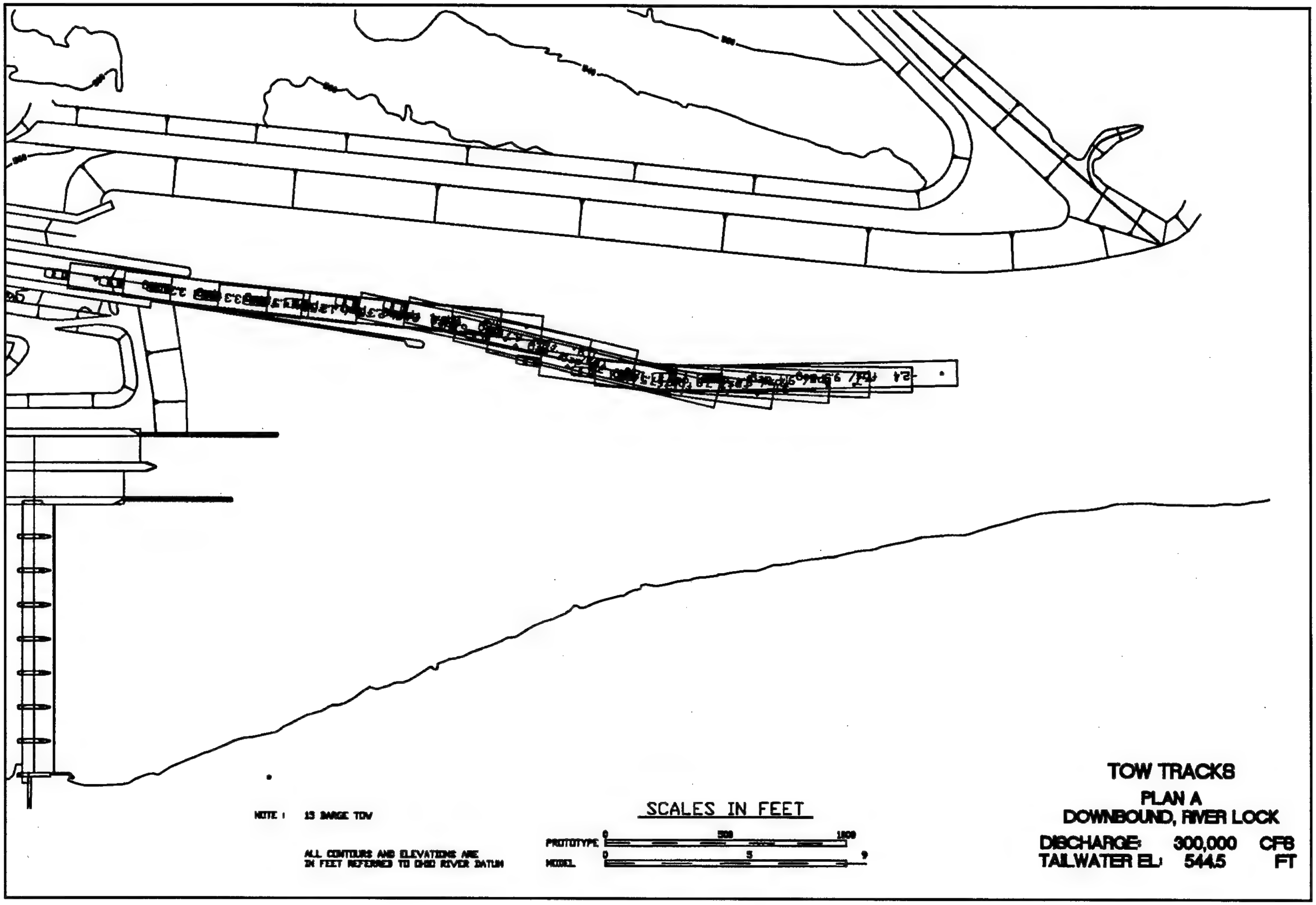

TOW TRACKS
PLAN A
DOWNBOUND, RIVER LOCK
DISCHARGE: 300,000 CFS
TAILWATER EL: 544.5 FT
NOTE : 13 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9

Plate 39

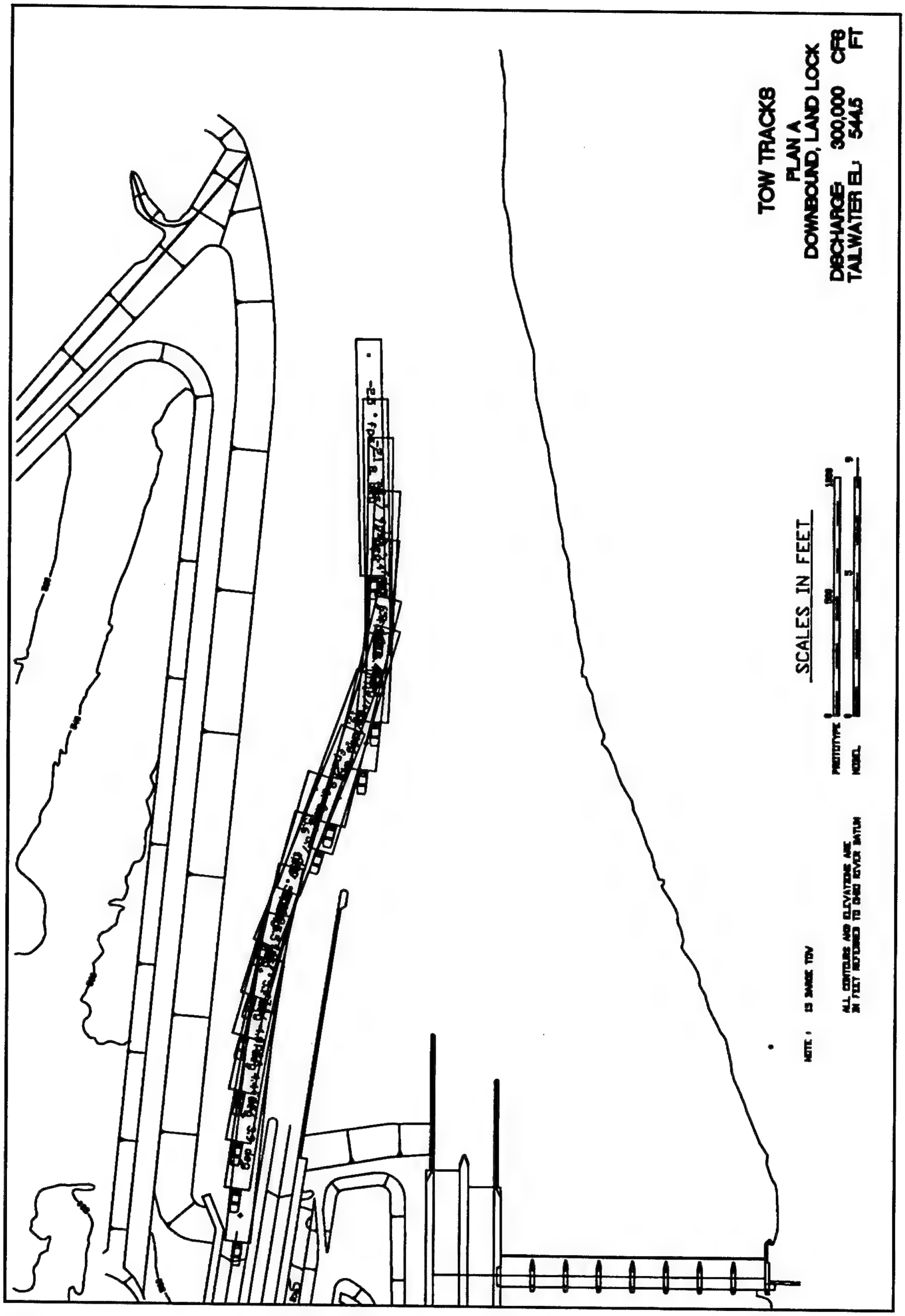
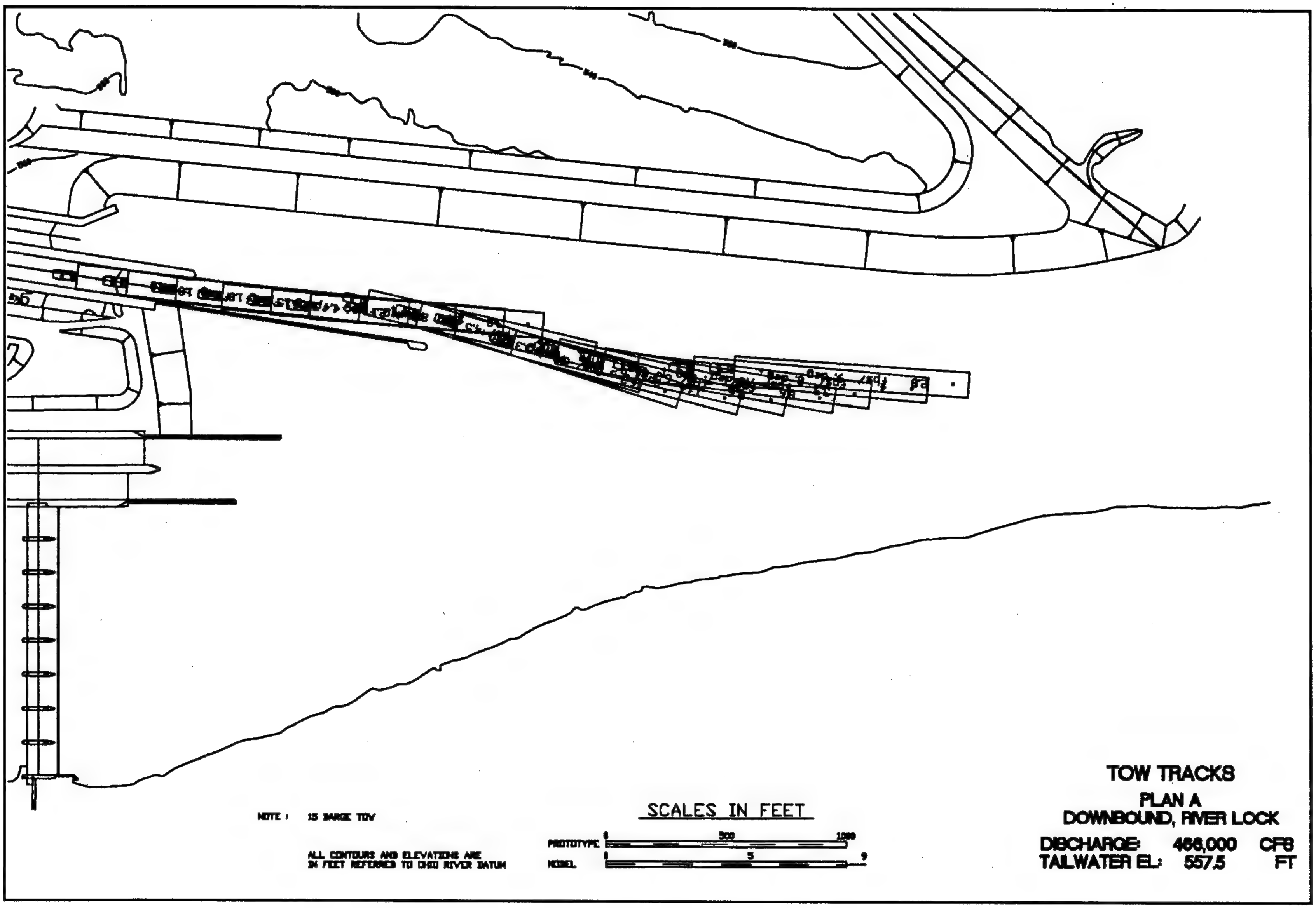

TOW TRACKS
PLAN A
DOWNBOUND, LAND LOCK
DISCHARGE 300,000 CFS
TAILWATER EL 544.5 FT
SCALES IN FEET

Plate 40


TOW TRACKS
PLAN A
DOWNBOUND, RIVER LOCK
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

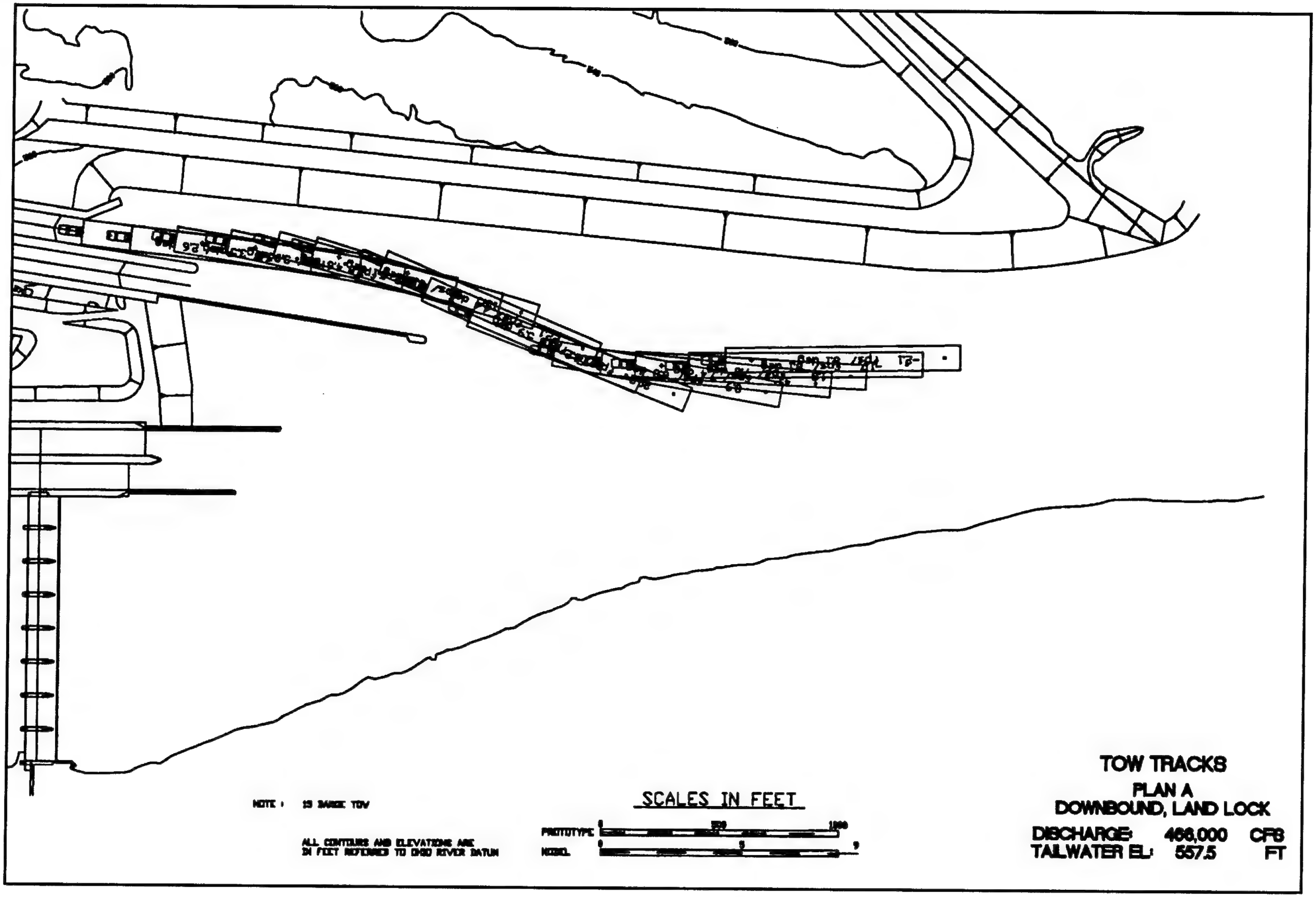
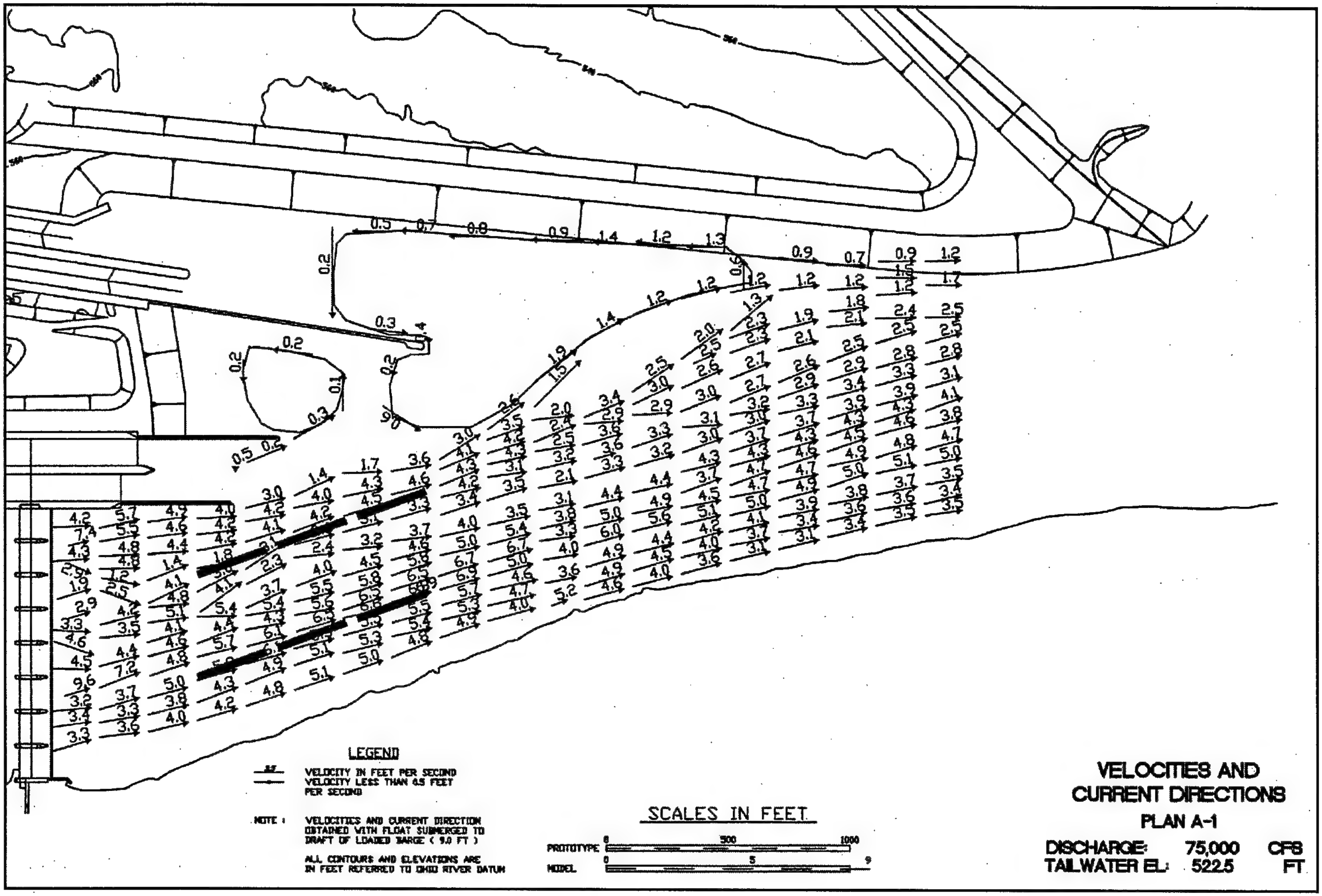

TOW TRACKS
PLAN A
DOWNBOUND, LAND LOCK
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
NOTE : 15 BARGE TOW
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate 42


LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
VELOCITIES AND CURRENT DIRECTIONS
PLAN A-1
DISCHARGE: 75,000 CFS
TAILWATER EL: 522.5 FT

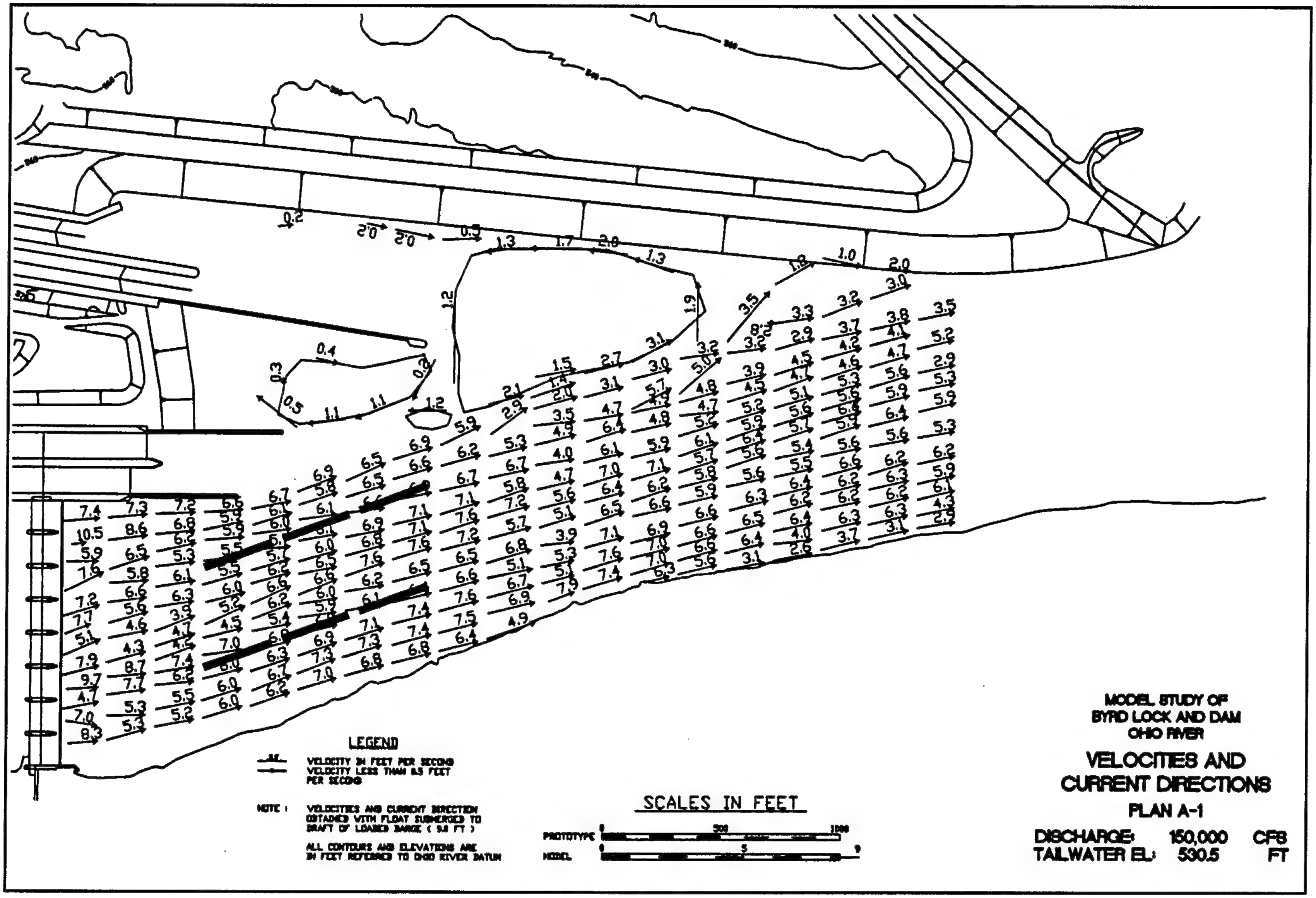
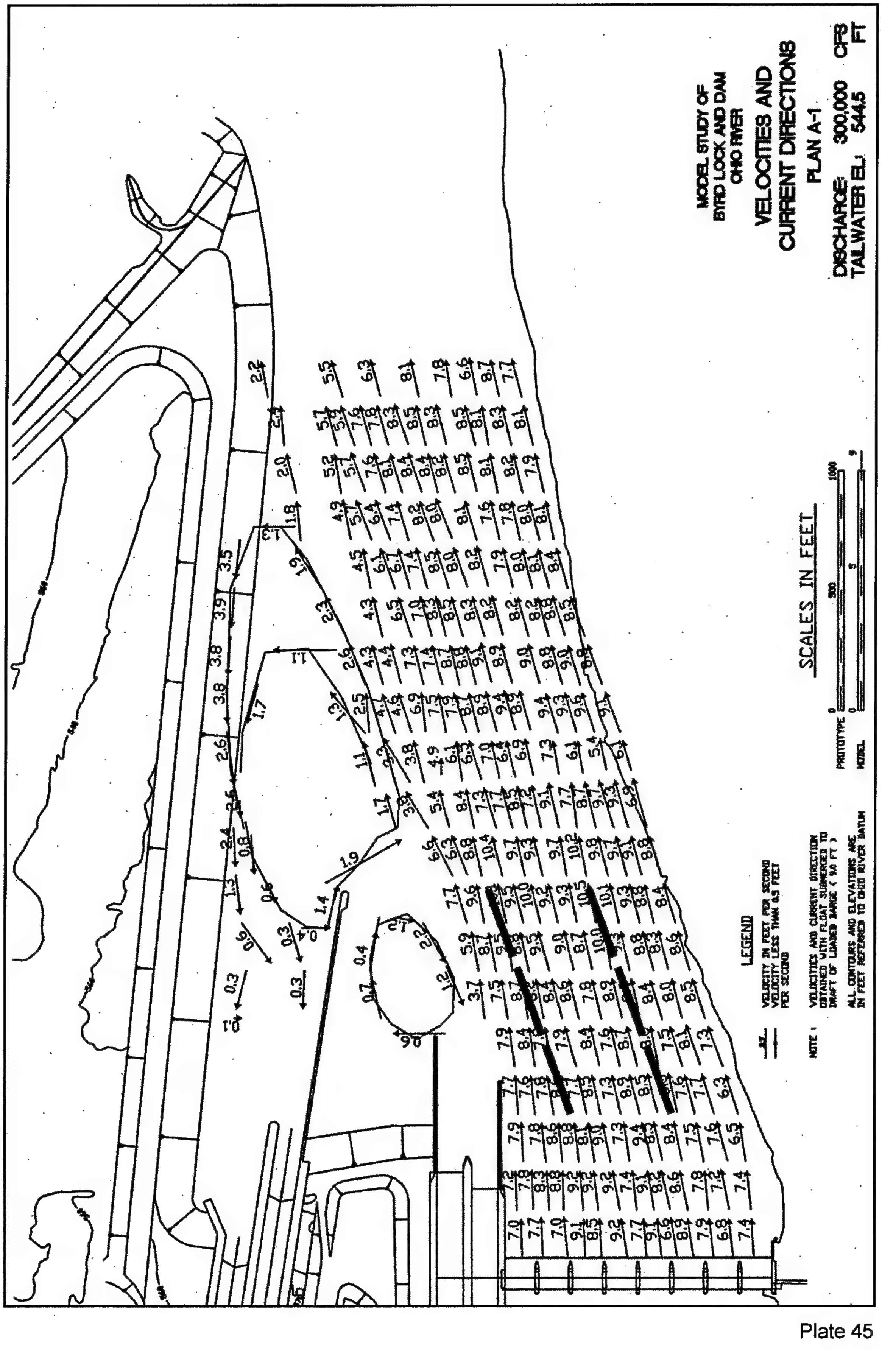
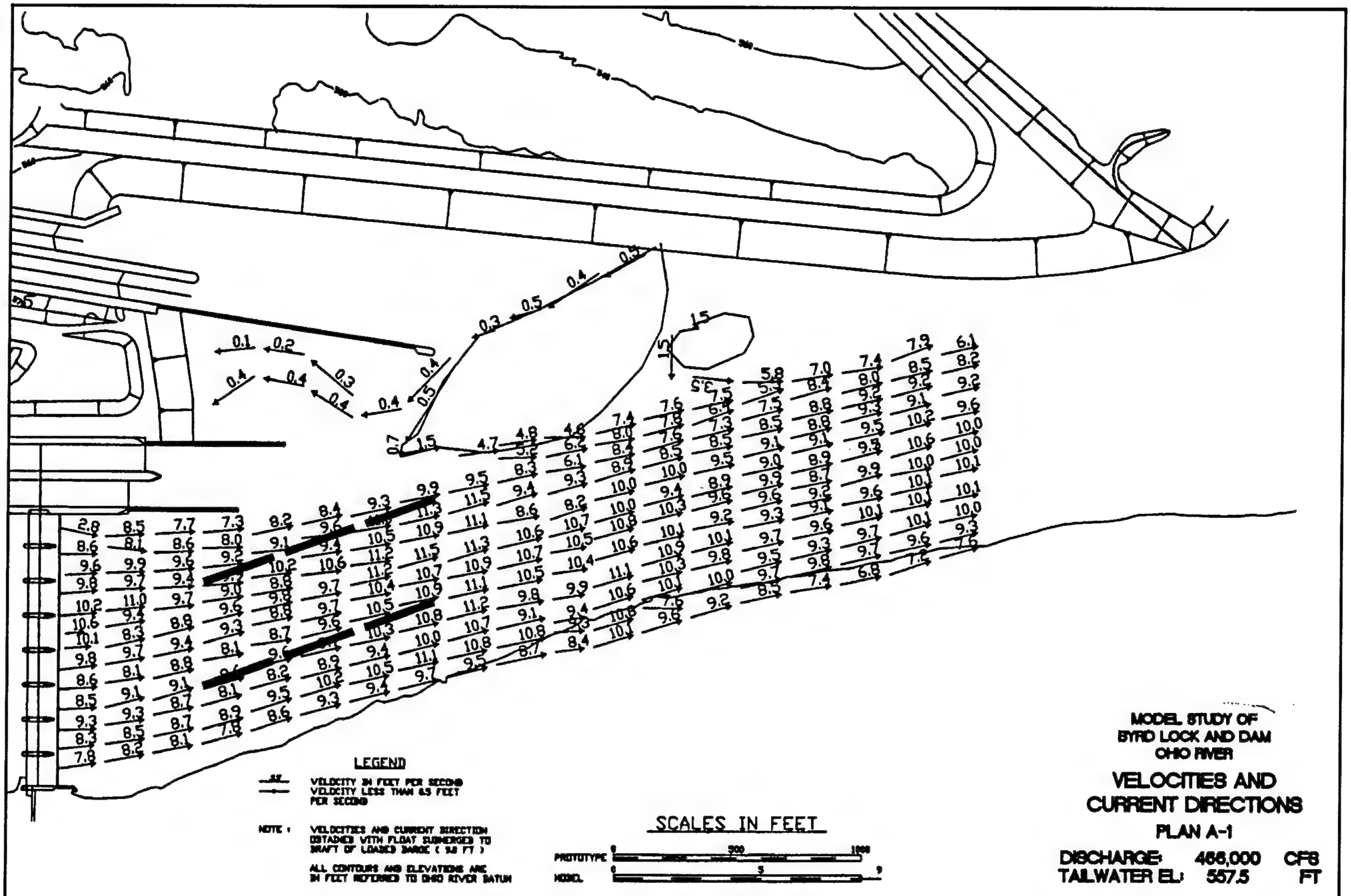

MODEL STUDY OF
BYRD LOCK AND DAM
OHIO RIVER
VELOCITIES AND
CURRENT DIRECTIONS
PLAN A-1
DISCHARGE: 150,000 CFS
TAILWATER EL: 530.5 FT
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE
MODEL

Plate 44


MODEL STUDY OF
BYRD LOCK AND DAM
OHIO RIVER
VELOCITIES AND
CURRENT DIRECTIONS
PLAN A-1
DISCHARGE 300,000 CFS
TAILWATER EL. 544.5 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM


LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 9
MODEL STUDY OF
BYRD LOCK AND DAM
OHIO RIVER
VELOCITIES AND
CURRENT DIRECTIONS
PLAN A-1
DISCHARGE: 466,000 CFS
TAILWATER EL: 557.5 FT

Appendix A
Stone Sizing and Gradation for Proposed Dikes

Following the completion of evaluation of the proposed dikes immediately downstream of the R. C. Byrd Dam in the fixed-bed navigation model, the U.S. Army Engineer Research and Development Center (ERDC) was requested to determine the stone sizing and gradation that would be acceptable for use to construct these dikes.

Point velocities had been obtained around the proposed dikes in the model with flow conditions up to 466,000 cfs, which is considered an annual flood event. The U.S. Army Engineer District, Huntington, was concerned that velocities at higher discharge events should be considered for use in determining the stone sizing. The Huntington District provided two additional flow conditions: 50-year event; 523,000 cfs at 562.0-ft tailwater and 100-year event; 556,000 cfs at 564.6-tailwater. ERDC was requested to operate the model with these flow conditions and obtain velocities around the dikes in a manner similar to that done with two flows (150,000- and 300,000-cfs) that were used to evaluate navigation conditions in the lower lock approach. Figure A1 shows the position of the collection sites and the velocities are presented in Table A1. Plates A1 and A2 are current direction and velocities recorded with the two flood flows.

In discussions between the Huntington District and ERDC concerning the stone sizing computations, ERDC requested that any standard stone sizing and gradations that were commonly available near the site be provided, along with any information concerning the makeup of the channel bottom where the dikes were proposed to be placed.

The following procedure was used to determine the stone size and gradation for the mitigation dikes at R. C. Byrd Locks and Dam. Determination of the D_{30} stone size is based on Equation 3-3, page 3-5 of EM 1110-2-1601.[1]

[1] U.S. Army Corps of Engineers. (1991). "Hydraulic design of flood control channels," EM 1110-2-1601, Washington, DC.

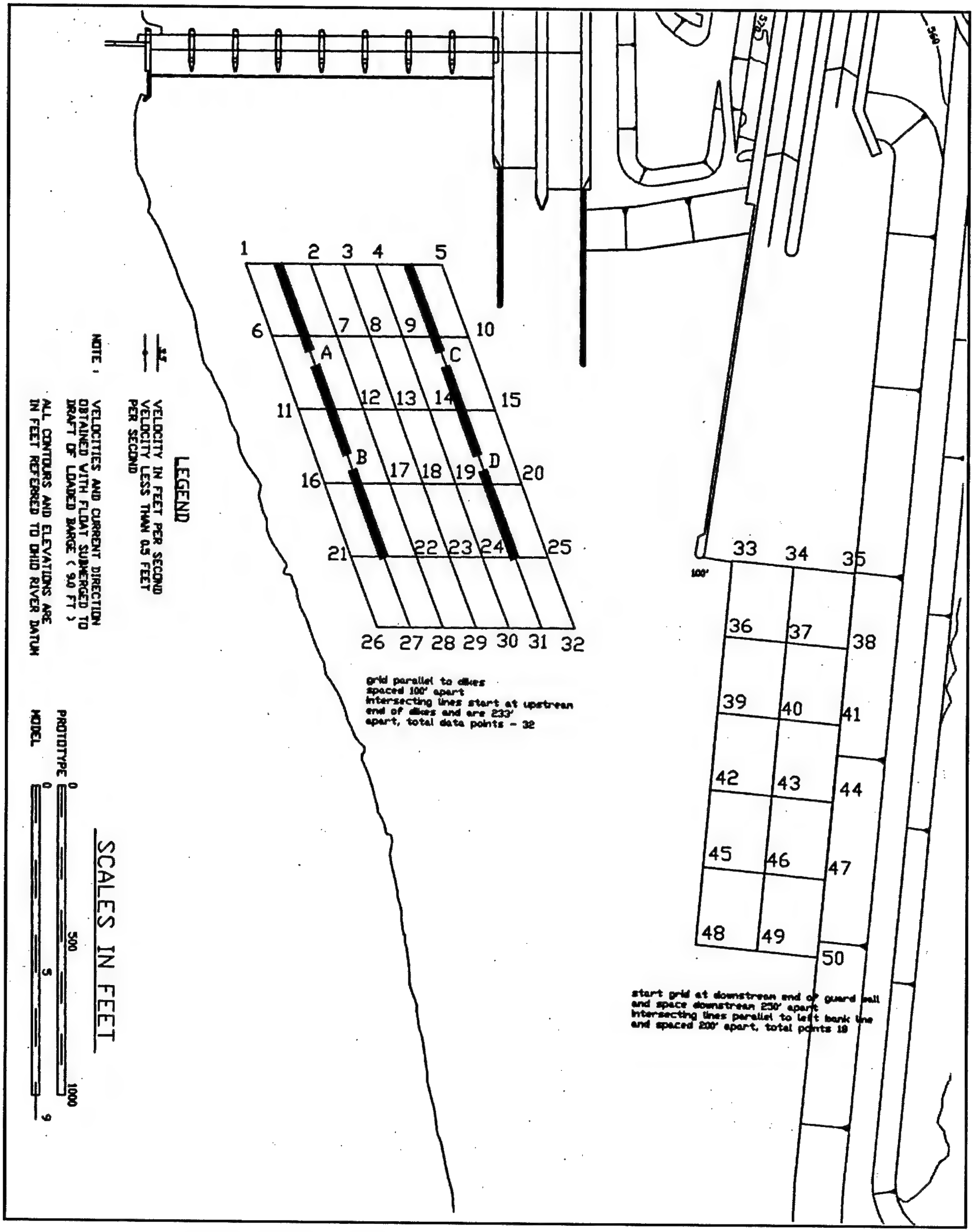


Figure A1. Point velocity collections sites

Table A1
Point Velocity Comparison

	6/10 Depth; Velocity, fps				8/10 Depth; Velocity, fps			
Pt. No.	150K cfs	300K cfs	523K cfs	556K cfs	150K cfs	300K cfs	523K cfs	556K cfs
1	4.6	6.4	6.8	6.7	4.5	6.3	6.6	6.6
2	4.9	7.7	8.9	8.9	4.8	7.5	8.6	8.7
3	5.0	7.3	8.3	8.2	5.0	7.1	8.0	7.6
4	4.7	6.5	7.3	7.3	4.3	6.2	7.2	7.2
5	5.2	8.0	8.9	9.2	5.0	7.3	8.2	8.5
6	5.4	6.7	7.5	7.2	5.3	7.2	7.2	6.9
7	5.5	7.6	8.2	8.5	5.4	7.7	8.5	8.7
8	5.3	8.0	9.2	9.2	5.2	8.0	9.2	9.2
9	5.4	8.5	9.6	9.6	5.2	8.2	9.4	9.3
10	5.1	7.0	7.8	7.8	5.1	6.8	7.5	7.8
11	5.9	8.0	8.9	9.0	5.8	7.6	8.5	8.5
12	6.0	7.6	8.5	8.5	5.8	7.4	8.3	8.2
13	5.3	7.7	8.7	8.7	5.5	7.5	8.7	8.7
14	5.4	7.6	9.0	9.0	5.4	7.7	9.2	9.2
15	5.5	7.3	8.0	7.4	5.2	6.8	7.4	7.4
16	6.2	8.4	9.0	8.8	6.2	8.3	9.3	8.6
17	6.4	8.4	9.6	9.4	6.3	8.0	9.2	8.9
18	5.9	8.4	9.4	9.3	5.7	8.2	9.0	8.7
19	5.3	7.7	8.1	8.1	5.4	8.0	8.1	8.4
20	5.6	7.1	7.3	7.2	5.2	6.8	6.9	6.9
21	6.4	8.3	8.9	8.7	6.0	8.2	9.0	8.7
22	5.8	8.5	9.3	9.3	5.5	7.9	9.3	8.9
23	5.4	8.5	9.2	9.3	5.1	8.0	9.0	8.8
24	4.6	7.2	8.6	8.4	4.7	7.2	8.2	7.9
25	5.1	6.0	6.2	6.2	4.4	5.3	6.0	6.1
26	6.1	8.2	8.7	8.6	5.7	8.1	8.8	7.7
27	3.6	7.4	9.2	8.6	3.2	6.5	8.5	7.2
28	5.8	8.5	9.4	9.2	5.4	8.3	9.2	8.4
29	5.4	8.3	9.1	9.0	5.0	8.2	9.0	8.0
30	4.5	7.2	8.3	8.0	4.7	7.0	7.9	7.1
31	3.5	5.8	7.0	6.2	3.2	5.1	6.0	4.9
32	4.3	4.2	5.1	4.9	3.6	3.9	4.8	4.1

Velocities Between Segments of Dikes, Plan A-1

	6/10 Depth; Velocity, fps		8/10 Depth; Velocity, fps	
Pt. No.	523K cfs	556K cfs	523K cfs	556K cfs
A	7.8	6.0	6.9	4.8
B	9.0	7.1	8.7	6.3
C	8.9	6.5	9.0	6.8
D	8.3	6.4	8.3	6.6

The values used for the terms of the equation and the explanation of how that value was arrived at are as follows:

S_f = safety factor, typically set at 1.1

C_s = Stability coefficient = 0.30 for angular rock

C_v = Vertical velocity distribution coefficient = 1.25 for ends of dikes

C_t = Thickness coefficient. In the case of stone fill dikes, the overall thickness will be greater than the D_{100} size, so the coefficient value is 1.0.

d = local depth of flow. The dikes have a crest elevation of 517.0, therefore the depth used for calculation is the tailwater elevation minus the dike crest elevation.

γ_w = unit weight of water, 62.43 lb/ft^3

γ_s = unit weight of stone. Unit weight assumed to be approximately 155 lb/ft^3. The unit weight of concrete is approximately 150 lb/ft^3.

V = local average velocity.

These velocities were obtained in the physical model by the use of an electromagnetic velocity meter recording at six-tenths depth with the proposed training dikes installed. The maximum average velocity within the dike field at this depth is used.

K_1 = side slope correction factor

g = gravitational constant, 32.2 ft/sec^2

K_1 is determined by the equation: $K_1 = (1 - ((\sin^2 \theta)/(\sin^2 \phi)))^{1/2}$

where:

θ = angle of side slope with horizontal

ϕ = natural angle of repose of riprap material, normally 40 deg.

The design of the proposed dikes specified a side slope of 1 on 2.5, an angle of 21.8 deg from the horizontal. This yields a value of K_1 to be 0.816.

Point velocities were obtained at six-tenths and eight-tenths depth for four flow conditions in the R. C. Byrd model with the proposed dikes in place. The flow conditions were as follows:

Discharge, cfs	Tailwater el	6/10 depth el	8/10 depth el
150,000	530.5	512.2	506.1
300,000	544.5	517.8	508.9
523,000	562.0	524.8	512.4
566,000	564.6	525.8	512.9

The velocity to be used for stone sizing calculations assumes the velocity at 20 percent of the distance along the slope from the bottom. The bottom of the channel is approximately el 500.0 and the crest of the dikes are el 517.0, therefore the distance from the bottom should be (17 × 0.20), 3.4 ft or el 503.4.

The highest point velocities obtained around the proposed dikes were as follows:

Discharge, cfs	6/10 depth	8/10 depth
150,000	6.4	6.3
300,000	8.5	8.3
523,000	9.6	9.4
566,000	9.6	9.3

The maximum velocities recorded at the six-tenths and eight-tenths were minimally different. The depth where the velocities were recorded was above the theoretical depth to be used for calculation of velocities. It was considered to be conservative to use the higher velocities recorded at the six-tenth depth. The velocities, as noted in the current directions and velocities, shown in Plates 23-26, were generally parallel to the alignment of the dikes, therefore the ratio of $V_{SS}/V_{AVG} = 1.0$.

A statement made in paragraph D, page F-10, of EM 1110-2-1601 states that the most logical procedure to be used in determination of stone sizing and gradation is to assume the minimum specific weight for stone that would meet all other design criteria. This weight was established to be 155 lb/cu ft. This specific weight is assumed for all calculations for stone sizing. If stone is only available in a higher specific weight, the margin of safety of the design would increase.

For the 150,000-cfs flow, using a depth of 13.5 ft, velocity of 6.4 fps and $\gamma_s = 155\ lb/ft^3$

$D_{30} = 0.229$ ft

For the 300,000-cfs flow, using a depth of 27.3 ft, velocity of 8.5 fps and $\gamma_s = 155\ lb/ft^3$

$D_{30} = 0.389$ ft

For the 523,000-cfs flow, using a depth of 45.0 ft, velocity of 9.6 fps and $\gamma_s = 155\ lb/ft^3$

$D_{30} = 0.466$ ft

For the 566,000-cfs flow, using a depth of 47.6 ft, velocity of 9.6 fps and $\gamma_s = 155\ lb/ft^3$

$D_{30} = 0.458$ ft

Table A2
Gradations for Riprap Placement in the Dry, Low-Turbulence Zones

Limits of StoneWeight, lb[1], for Percent Lighter by Weight								
D_{100}(max) in.	100 Max	100 Min	50 Max[2]	50 Min	15 Max[2]	15 Min	D_{30}(min) ft	D_{90}(min) ft
Specific Weight = 155 pcf								
12	81	32	24	16	12	5	0.48	0.70
15	159	63	47	32	23	10	0.61	0.88
18	274	110	81	55	41	17	0.73	1.06
21	435	174	129	87	64	27	0.85	1.23
24	649	260	192	130	96	41	0.97	1.40
27	924	370	274	185	137	58	1.10	1.59
30	1,268	507	376	254	188	79	1.22	1.77
33	1,688	675	500	338	250	105	1.34	1.94
36	2,191	877	649	438	325	137	1.46	2.11
42	3,480	1,392	1,031	696	516	217	1.70	2.47
48	5,194	2,078	1,539	1,039	769	325	1.95	2.82
54	7,396	2,958	2,191	1,479	1,096	462	2.19	3.17
Specific Weight = 165 pcf								
12	86	35	26	17	13	5	0.48	0.70
15	169	67	50	34	25	11	0.61	0.88
18	292	117	86	58	43	18	0.73	1.06
21	463	185	137	93	69	29	0.85	1.23
24	691	276	205	138	102	43	0.97	1.40
27	984	394	292	197	146	62	1.10	1.59
30	1,350	540	400	270	200	84	1.22	1.77
33	1,797	719	532	359	266	112	1.34	1.96
36	2,331	933	691	467	346	146	1.46	2.11
42	3,704	1,482	1,098	741	549	232	1.70	2.47
48	5,529	2,212	1,638	1,106	819	346	1.95	2.82
54	7,873	3,149	2,335	1,575	1,168	492	2.19	3.17
Specific Weight = 175 pcf								
12	92	37	27	18	14	5	0.48	0.70
15	179	72	53	36	27	11	0.61	0.88
18	309	124	92	62	46	19	0.73	1.06
21	491	196	146	98	73	31	0.85	1.23
24	733	293	217	147	109	46	0.97	1.40
27	1,044	417	309	209	155	65	1.10	1.59
30	1,432	573	424	286	212	89	1.22	1.77
33	1,906	762	565	381	282	119	1.34	1.94
36	2,474	990	733	495	367	155	1.46	2.11
42	3,929	1,571	1,164	786	582	246	1.70	2.47
48	5,864	2,346	1,738	1,173	869	367	1.95	2.82
54	8,350	3,340	2,474	1,670	1,237	522	2.19	3.17

Notes:
[1] Stone weight limit data from ETL 1110-2-120 (HQUSACE, 1971 (14 May), "Additional Guidance for Riprap Channel protection, Ch 1," U.S. Government Printing Office, Washington, DC). Relationship between diameter and weight is based on the shape of a sphere.
[2] The maximum limits at the W_{50} and W_{15} sizes can be increased as in the Lower Mississippi Valley Division Standardized Gradations shown in Appendix F.

Note: This table is taken from Table 3-1, EM 1110-2-1601.

The highest D_{30} was obtained with the 523,000-cfs flow condition, therefore the minimum D_{30} size acceptable is 0.466 ft. Table A2 lists gradations based on minimum D_{30} size. In this table, with $\gamma_s = 155\ \text{lb/ft}^3$, the D_{30} that exceeds that of

the calculation is 0.48 ft. This value yields a D_{100}(max) of 12 in., a maximum W_{100} of 81 lb. and a minimum W_{15} of 5 lb.

This particular method of determination of stone sizing has not been verified when the flow depth is many times greater than the rock size, which in the case of a 45-ft depth would be approximately 97 times greater than the stone size of 0.466 ft. An alternate method of determination of stone sizing is to use the Isbash equation and bottom velocity if available. Hydraulic Design Chart 712-1, Plate B-29, EM 1110-2-1601 (Plate A2) was developed using this equation to quickly determine the D_{50} size of stone based on specific weight, average bottom velocity, and low turbulence. Using the eight-tenths depth velocity of 9.4 fps for the 523,000-cfs flow condition and a specific weight of 155 lb/cu ft, the D_{50} size for stone would be 0.65 ft.

ERDC was provided specifications for stone gradations from the Ohio Department of Transportation (ODOT). These specifications outlined four general gradations of stone.

These gradations are:

Type	D_{85}	D_{50}	D_{15}
A	<30 in.	>24 in.	<18 in.
B	<24 in.	>18 in.	<12 in.
C	<18 in.	>12 in.	<6 in.
D	<12 in.	>6 in.	<3 in.

These gradations were plotted as gradation curves on a standard gradation plot form as illustrated in Plate B-32 of EM 1110-2-1601 (Plate A4). The stone size was converted to theoretical weight using theoretical stone size diameter versus the specific stone weight curves that are printed on the gradation curve form. The minimum and maximum weights at the 100, 50, and 15 percent lighter that are listed with the D_{30} of 0.48 ft (from Table A2) were also plotted on this form, along with the D_{50} size of 0.65 ft obtained from Chart 712-1. The Type D gradation stone is too light based on both the Engineer Manual guidance and the Isbash guidance. The Type C stone gradation is the smallest gradation that exceeds the required stone size from both the EM and the Isbash equations.

Table A2 was derived for stone being placed in the dry and anticipated to be used in a low turbulence area. The area that the proposed dikes are to be constructed will be in the wet and will experience some turbulence due to the proximity of the dam and stilling basin. Table A3 lists gradations of stone and thickness of stone based on anticipation of high turbulence zones. The W_{100} of 81 lb. as obtained from Table 3-1 of EM 1110-2-1601 for low turbulence zones would required a minimum stone thickness of 18 in. in the high turbulence zone. This only applies to using the standard gradation from the Engineer Manual.

Table A3
Gradations for Riprap Placement in the Dry High Turbulence Zones

Percent Lighter by Weight	Limits of Stone Weight, pounds		Limits of Stone Weight, pounds		Limits of Stone Weight, pounds		Limits of Stone Weight, pounds	
	Specific Weight = 155 lb/cu ft							
Thickness =	12 Inches		15 Inches		18 Inches		21 Inches	
100	24	10	47	19	81	32	129	52
50	7	5	14	9	24	16	38	26
15	4	2	7	3	12	5	19	8
Thickness =	24 Inches		27 Inches		30 Inches		33 Inches	
100	192	77	274	110	376	150	500	200
50	57	38	81	55	111	75	148	100
15	28	12	41	17	56	23	74	31
Thickness =	36 Inches		42 Inches		48 Inches		54 Inches	
100	649	260	1,031	412	1,539	616	2,191	877
50	192	130	305	206	456	308	649	438
15	96	41	153	64	228	96	325	137
Thickness =	60 Inches		66 Inches		72 Inches		78 Inches	
100	3,006	1,202	4,001	1,600	5,194	2,078	6,604	2,642
50	890	601	1,185	800	1,539	1,039	1,957	1,321
15	445	188	593	250	770	325	978	413
Thickness =	84 Inches		90 Inches		96 Inches		102 Inches	
100	8,248	3,299	10,145	4,058	12,312	4,925	14,768	5,907
50	2,444	1,650	3,006	2,029	3,648	2,462	4,376	2,954
15	1,222	516	1,503	634	1,824	770	2,188	923
	Specific Weight = 165 lb/cu ft							
Thickness =	12 Inches		15 Inches		18 Inches		21 Inches	
100	26	10	50	20	86	35	137	55
50	11	5	21	10	36	17	58	27
15	5	2	11	3	18	5	29	9
Thickness =	24 Inches		27 Inches		30 Inches		33 Inches	
100	205	82	292	117	400	160	532	213
50	86	41	123	58	169	80	225	106
15	43	13	62	18	84	25	112	33

Note: This table is taken from a portion of Table 5-3, EM 1110-2-1605.

In high turbulence zones, thickness is 1.5 D_{100} (max) or 2.0 D_{50} (max), whichever is greater. For ODOT Type C gradation, the minimum thickness will be the 1.5 (18 in.) = 27 in. Information provided by the Huntington District indicated that the channel bottom is mostly gravel. This type of bed would tend

to minimize any scour at the base of the dikes which require additional stone thickness to allow for launching.

The Type C stone has a substantial safety factor when comparing actual stone size to computed stone size. This safety factory should alleviate concerns about the proximity of the dikes to the stilling basin and the use of a low turbulence coefficient in the Isbash equation.

In summary, based on velocities obtained from the R. C. Byrd model with the proposed dikes in place and calculations of stone size and gradations, the following was determined:

a. The maximum velocity recorded around the dikes at 6/10 depth was 9.6 fps with a 523,000-cfs flow condition.

b. Using this velocity and the depth crest of the dike below the tailwater elevation for the 523,000-cfs flow (45.0 ft), the D_{30} (min) required will be 0.466 ft using EM 1110-2-1601.

c. The D_{50} size of stone based on Hydraulic Design Chart 712-1 is 0.65 ft.

d. Using standard gradations from Table 3-1 of EM 1110-2-1601, the closest D_{30} (min) that exceeds the calculated value of 0.466 ft is 0.48 ft with a maximum W_{100} of 81 lb. and a minimum W_{15} of 5 lb.

e. Comparison of the required D_{30} of 0.466 ft, D_{50} (min) of 0.65 ft, and the gradation types from ODOT on a standard gradation plot indicates that the Type C ODOT gradation is acceptable.

f. Using Table A3 (Table 5-3 from EM 1110-2-1605) for high turbulence zones and the stone gradation obtained from Table A2 (Table 3-1 of EM 1110-2-1601), the minimum thickness for the stone should be 18 in. if using standard gradations.

g. Stone thickness based on using ODOT Type C gradation will be a minimum of 27 in.

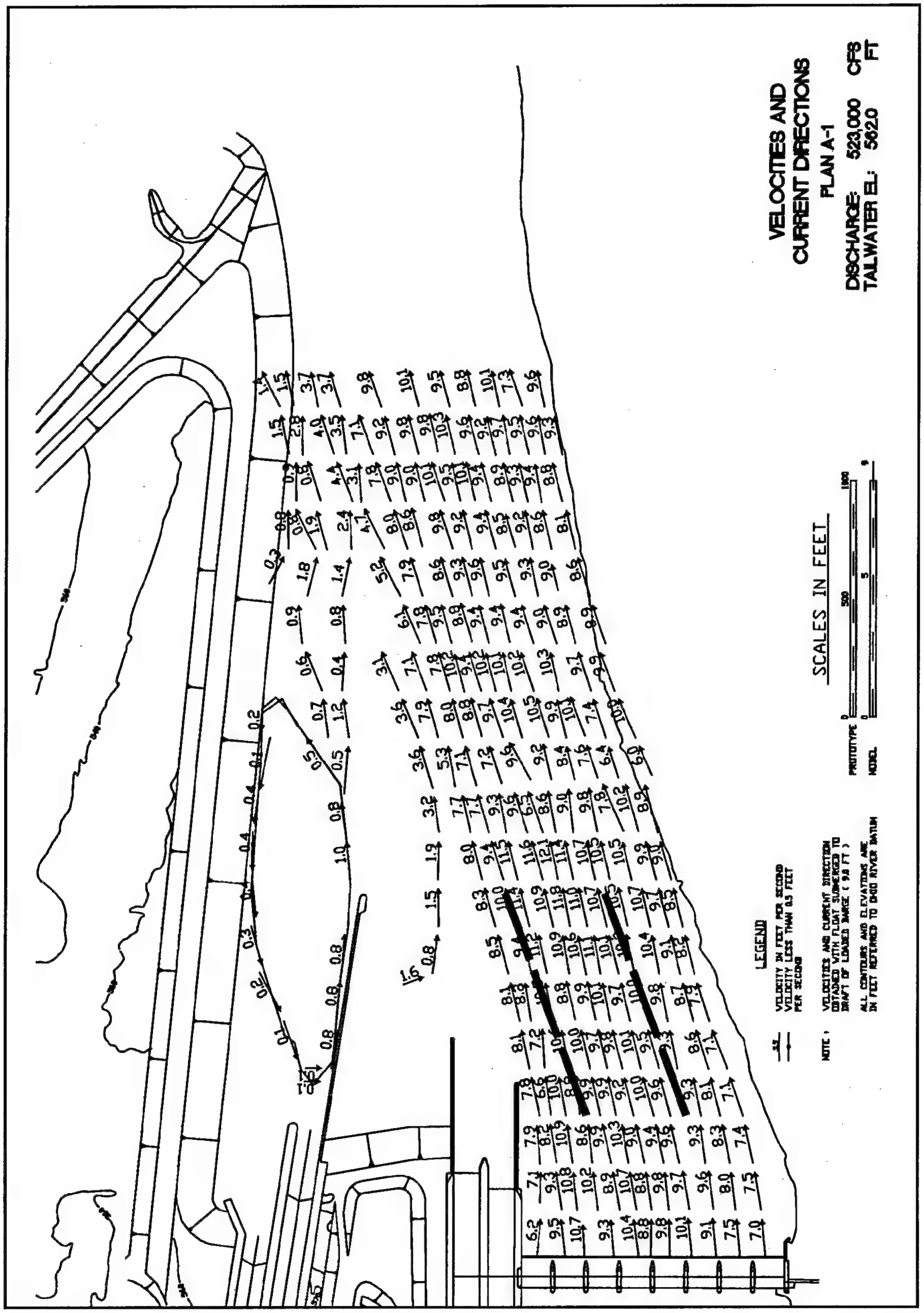

VELOCITIES AND
CURRENT DIRECTIONS
PLAN A-1
DISCHARGE: 523,000 CFS
TAILWATER EL.: 562.0 FT
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate A1

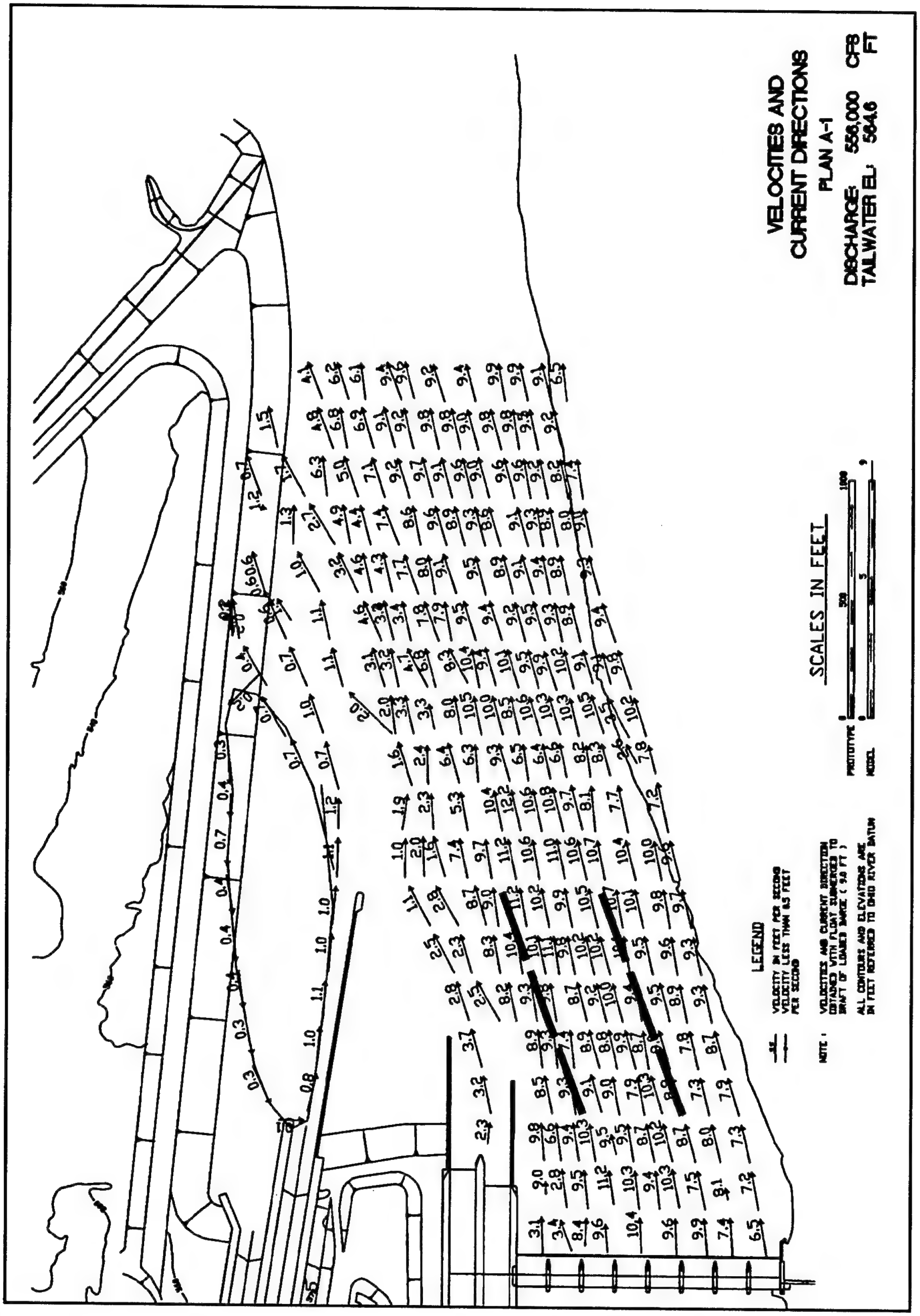
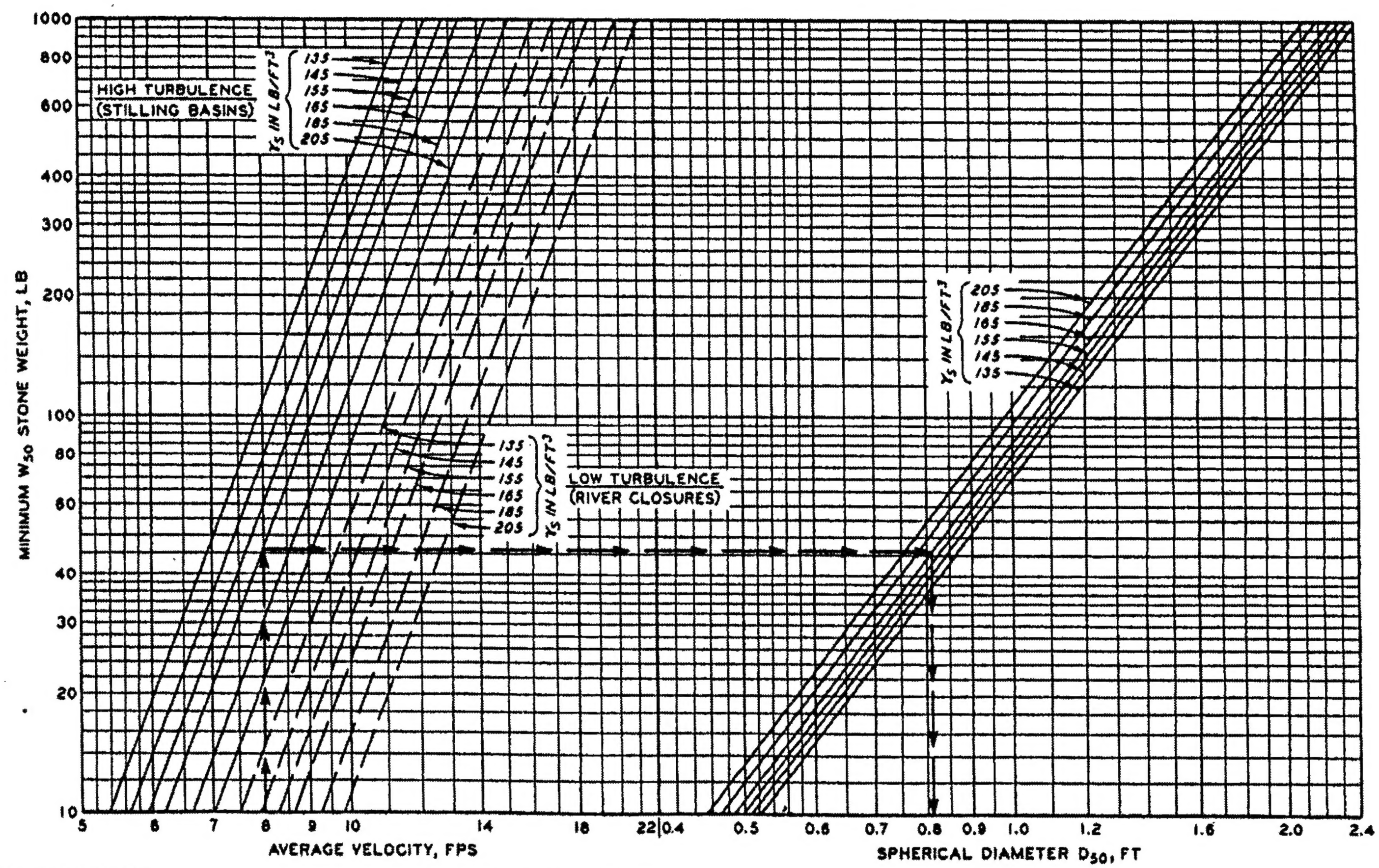

VELOCITIES AND
CURRENT DIRECTIONS
PLAN A-1
DISCHARGE: 556,000 CFS
TAILWATER EL. 564.6 FT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

Plate A2



PREPARED BY U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI

BASIC EQUATIONS

$$V = C\left[2g\left(\frac{\gamma_s - \gamma_w}{\gamma_w}\right)\right]^{1/2}(D_{50})^{1/2}$$

$$D_{50} = \left(\frac{6W_{50}}{\pi\gamma_s}\right)^{1/3}$$

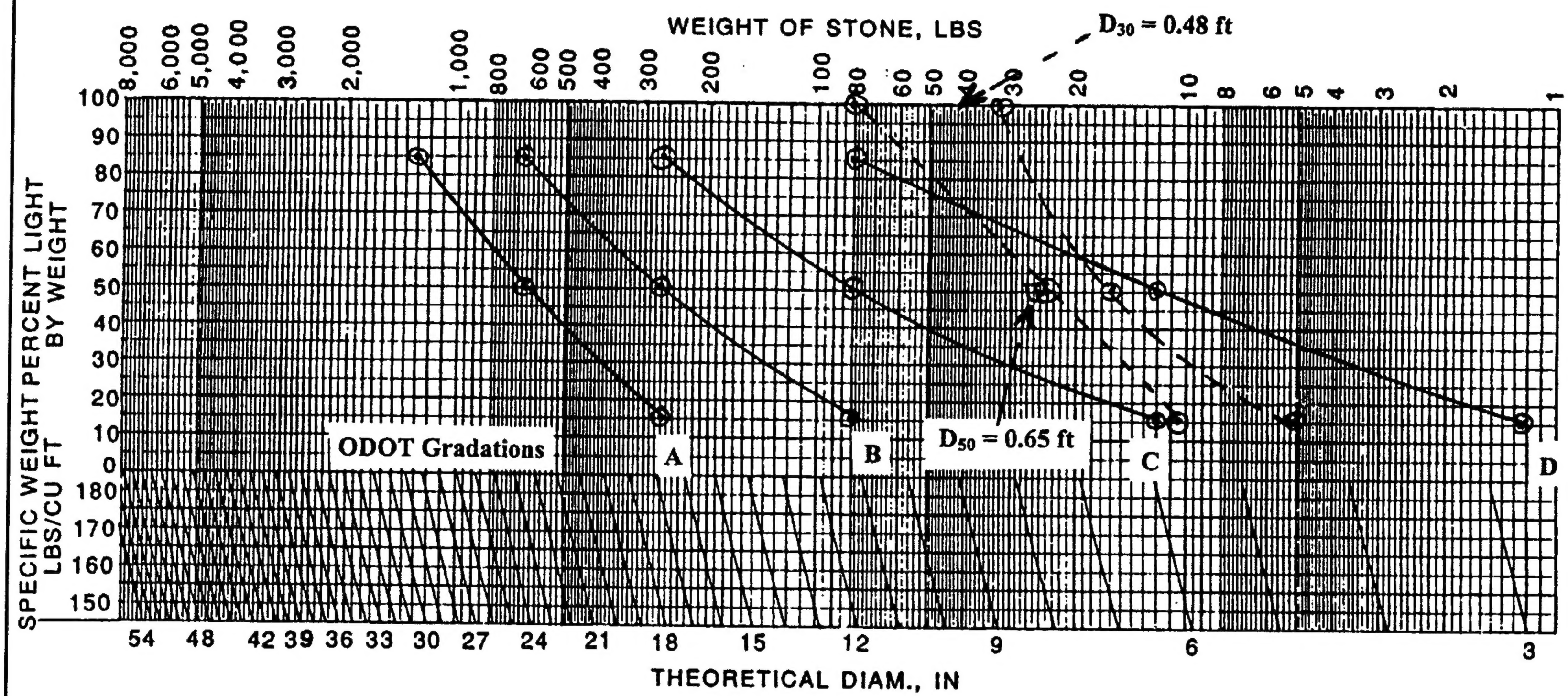
WHERE:
- V = VELOCITY, FPS
- γ_s = SPECIFIC STONE WEIGHT, LB/FT^3
- γ_w = SPECIFIC WEIGHT OF WATER, 62.5 LB/FT^3
- W_{50} = WEIGHT OF STONE. SUBSCRIPT DENOTES PERCENT OF TOTAL WEIGHT OF MATERIAL CONTAINING STONE OF LESS WEIGHT.
- D_{50} = SPHERICAL DIAMETER OF STONE HAVING THE SAME WEIGHT AS W_{50}
- C = ISBASH CONSTANT (0.86 FOR HIGH TURBULENCE LEVEL FLOW AND 1.20 FOR LOW TURBULENCE LEVEL FLOW)
- g = ACCELERATION OF GRAVITY, FT/SEC^2

STONE STABILITY
VELOCITY VS STONE DIAMETER

HYDRAULIC DESIGN CHART 712-1
(SHEET 1 OF 2)

REV 8-58, 9-70

WES 9-57



SPECIFIC WEIGHT OF STONE 155 LBS/CU FT

PROJECT Greenup Env. Mit.
AREA R.C. Byrd
DATE 12/2001 BY

RIPRAP GRADATION CURVES

Plate A4

REPORT DOCUMENTATION PAGE

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Studies were performed using the existing 1:120 physical navigation model of the R.C. Byrd Locks and Dam. The model study was performed primarily to determine navigation conditions that would be associated with the construction of proposed dikes immediately downstream of the dam. These dikes would be built as environmental mitigation habitat to compensate for areas that are to be taken for the Ohio River Main Stem Study project. The proposed dikes could not adversely affect navigation conditions in the lower lock approaches. The model was also used to indicate whether the dikes would affect sediment shoaling in the lock approaches. This was done by the use of a plastic tracer bead material. The model was also used to obtain current velocities around the proposed dikes. These velocities were then used to determine the stone sizing and gradation required for construction of these dikes, which is presented in Appendix A.

15. SUBJECT TERMS
See reverse.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
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Standard Form 298 (Rev. 8-98)
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15. (Concluded)

Dikes
Environmental mitigation
Flow patterns
Navigation
Ohio River
R. C. Byrd Locks and Dam
Sediment
Stone gradation
Stone size